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DESIGN OF COST-EFFECTIVE WATER QUALITY SURVEILLANCE SYSTEMS

Charles V. Beckers, et al

Raytheon Company

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16. Abstract

This report presents the development and successful demonstration of quantitative methods for the design of river basin water quality surveillance systems for pollution abatement. The methods provide a systematic approach to the consideration of expected stream conditions, system characteristics, equipment performance, and cost in the selection of a preferred system design from among a number of candidates. In the systems approach, the total system is evaluated for cost and effectiveness. Mathematics previously developed to describe the effectiveness of sampling is used. The analysis of performance draws heavily on reliability and maintainability technology. Data availability remains a constraint to the general application of the methods. The methods are computerized and the computer programs are detailed ~~in this report~~. They make use of the information available from the computerized river basin models now under general development. They are demonstrated to function satisfactorily on the Beaver River Basin when artificial data ~~is~~ are used to supplement the data base. It is concluded that the methods are acceptable for use by governmental water quality agencies under the existing constraints. ~~The report includes 31 references. This report is submitted in fulfillment of Contract Number 68-01-0703, by the Raytheon Company, Oceanographic & Environmental Services Department, Portsmouth, RI, under the sponsorship of the Environmental Protection Agency.~~ (EPA)

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DESIGN OF COST-EFFECTIVE WATER QUALITY SURVEILLANCE SYSTEMS

By

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Contract No 68-01-0703
Program Element 1BA030

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ABSTRACT

This report presents the development and successful demonstration of quantitative methods for the design of river basin water quality surveillance systems for pollution abatement. The methods provide a systematic approach to the consideration of expected stream conditions, system characteristics, equipment performance, and cost in the selection of a preferred system design from among a number of candidates.

The methods are based on a systems approach in which the total system is evaluated for cost and effectiveness. They make extensive use of mathematics previously developed to describe the effectiveness of sampling in the context of abatement. The analysis of candidate system performance draws heavily on reliability and maintainability engineering technology. Data availability remains a constraint to the general application of the methods, but acquisition of the necessary data is wholly within the prerogatives of governmental agencies operating monitoring systems.

The methods are computerized and the computer programs are detailed in this report. They make use of the information available from the computerized river basin models now under general development.

The computerized design methods are demonstrated to function satisfactorily on the Beaver River Basin when artificial data is used to supplement the data base. It is concluded that the methods are acceptable for use by governmental water quality agencies under the existing constraints.

This report is submitted in fulfillment of Contract Number 68-01-0703, by the Raytheon Company, Oceanographic and Environmental Services Department, Portsmouth, RI, under the sponsorship of the Environmental Protection Agency.

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International Mathematical and Statistical Libraries, Inc., Houston, Texas 77036, is thanked for permission to incorporate a limited number of subroutines from their mathematical subroutine library in the computer programs prepared for government use.

SECTION I

CONCLUSIONS

The quantitative methods for design of river basin water quality surveillance systems developed in this report constitute a start-to-finish approach to the design of monitoring systems meeting the requirements of pollution abatement. They incorporate all the major factors influencing the system designer in his choice of design options and provide reasonable guidelines for the assessment of those factors.

The computer programs implementing those methods achieve their goal of reducing the computational labor involved in design analysis and of making the methodology tractable. They successfully make use of the information available from computerized river basin models.

The methods and the computer programs are successfully demonstrated for artificial data on the Beaver River Basin of Ohio and Pennsylvania.

Their utility remains limited by the availability of data on the performance of system components, but acquisition of these data is entirely within the prerogatives of the governmental agencies operating such systems.

The methods and computer programs are not immutable; they are expected to be modified by the user and to benefit from the experience gained in their application to real design problems. They provide a core methodology for use by the system designer.

SECTION II

RECOMMENDATIONS

The limitations placed on the application of the design methods by data availability should be removed. A research project directed at the acquisition and analysis of data on the reliability and maintainability of surveillance system components would provide valuable information both for use in monitoring system planning and for the improvement of the technology.

The methods should be actively applied to the analysis of existing and new surveillance systems. Such application can be expected to lead to cost-effective allocation of resources and to evolutionary improvement of the methods themselves.

Further research and development should be undertaken to provide a similar body of design methods for the direct monitoring of effluent sources. The effluent monitoring design methods should be complementary to the existing instream methods. Together, they should provide a total capability for the optimization of resource allocation between and within the two classes of water quality monitoring.

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SECTION III

INTRODUCTION

The Federal Water Pollution Control Act, as amended, calls for the Administrator of the Environmental Protection Agency, in cooperation with a number of federal and state agencies, to "establish, equip, and maintain a water quality surveillance system for the purpose of monitoring the quality of the navigable waters and ground waters and the contiguous zone and the oceans . . . ."[1] The act is the latest successor to a series of legislative responses to the increasing public awareness and concern for the quality of the environment. The water quality surveillance system called for constitutes only one element of a broad-ranging, federal-state program to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters."[1]

Water quality surveillance is essential to the success of this initiative toward environmental quality. William T. Sayers has pointed out that monitoring of ". . . the rivers, lakes, and coastal waters receiving wastes [is required] to assure attainment and maintenance of desired water quality levels consistent with criteria contained in state-federal water quality standards." [2] He further states the aims of water quality surveillance are ". . . to assess existing water quality conditions, to determine long-term trends in water quality and to evaluate compliance with state-federal water quality standards."

In order to promote the development of cost-effective surveillance systems, the Environmental Protection Agency is supporting a program aimed at providing system designers with methods for planning such surveillance systems. This report is one of several recent studies undertaken with EPA support to examine the question of design of water quality data acquisition systems. It is the second of two studies undertaken by Raytheon Oceanographic and

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Environmental Services to provide the design methods. The first Raytheon report [3] and two other related reports [4, 5] are reviewed in Section IV to provide the necessary background for the present study.

Such water quality surveillance systems may be directed at either of two general objectives: prevention or abatement [4]. Prevention refers to those actions aimed at maintaining the existing (presumable good) water quality. Abatement, on the other hand, refers to those actions directed at reducing or moderating existing pollution conditions.

This report is directed at the design of abatement-type water quality surveillance systems for river basins. It is intended to extend the quantitative methods of the previous Raytheon study [3] to include cost and effectiveness, and to computerize those methods. The implications of these objectives are discussed in detail in Section V, along with the approach taken in achieving the objectives.

Section VI, supported by Appendices B, C and D, presents the development of the quantitative cost-effectiveness methods, as applied to water quality surveillance systems. These included the consideration of such aspects as system accuracy, reliability, maintenance, survival, cost, and resource diversions.

The cost-effectiveness methods are merged with the previously developed preliminary design methods and presented as a unified design method in Section VII. To accommodate the merger, some modifications of the earlier preliminary design methods are required. They are detailed in Section VII.

Also presented in Section VII is a summary of the computer programs developed to implement the design methods. Instructions are provided for the preparation of input data and the use of the programs. Program development details may be found in Appendix E, which provides the reader with the criteria and considerations necessary to the preparation of the programs contained in Appendix F.

Included in Appendix E are special algorithms used in the implementation of the quantitative design methods.

The design of a cost-effective surveillance system using the quantitative methods is demonstrated in Section VIII. The demonstration is conducted on the Beaver River Basin of Ohio and Pennsylvania. A final discussion of the results of the study and its predecessors is contained in Section IX.

SECTION IV

REVIEW OF PREVIOUS DEVELOPMENT

In order to provide the reader with a background for the development presented in this report, several related reports are reviewed in this section. The present study is a direct outgrowth and expansion of a previous study by Raytheon Oceanographic and Environmental Services, reported in [3]. It is related to two other EPA studies [4, 5] and must be viewed in the context of general research on the design of water quality monitoring systems, such as [6]. In addition, it makes use of a computerized river basin model (RIBAM) developed by Raytheon Oceanographic and Environmental Services for the EPA and described in [7]. Each of these related studies is reviewed in this section.

The review is organized in a logical manner, rather than by publication date. This allows the use of a somewhat tutorial presentation, aimed at the establishment of a baseline for the development of later sections.

The overall objective of four of the five reports reviewed in this section [3, 4, 5, 6], as well as this report, is the development of concepts and methods to guide systems designers in the preparation of plans for water quality monitoring of river basins. The specific approaches and the desired results are conditioned on the objectives of the monitoring system, which are in turn dependent upon the objectives of the operating agency.

Ward [4] has categorized the state water pollution control programs according to two broad objectives: 1) prevention and 2) abatement. Within each of these broad program objectives, he identifies several, more specific functions of state programs. Table 1 summarizes the relationships among the functions and objectives. As indicated in the table, the data acquisition function is associated with both

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Table 1. RELATIONSHIP BETWEEN FUNCTIONS AND OBJECTIVES OF STATE PROGRAMS (after [4])

Function	Objective	
	Prevention	Abatement
Planning	X	
Research	X	
Aid programs	X	
Technical assistance		X
Regulation		X
Legal enforcement		X
Data collection, processing, dissemination	X	X

objectives. Specific data collection activities must be tailored to the broader of the two objectives to be satisfied by those activities.

The water quality monitoring systems considered in [3, 4, 5, 6] emphasize in-stream observation of water quality for pollution abatement. This emphasis is in contrast to use a direct effluent sampling as a means of pollution abatement. It is a result of the limitations of all but the most recent Federal water quality legislation. Prior to the enactment of the Federal Water Pollution Control Act Amendments of 1972 [8], the Federal Water Pollution Control Act [9] authorized only the establishment and enforcement of stream water quality standards. Thus, the concern has been for design of surveillance systems providing in-stream observations. With the passage of the Amendments of 1972 [8], the abatement of pollution through the establishment and enforcement of effluent standards (in conjunction with stream standards) gained legal recognition. Further efforts are required to develop comparable design methods for augmenting in-stream surveillance with effluent surveillance.

In addition to abatement, the observation of stream conditions is essential to the performance of prevention-type functions. In general, surveillance systems aimed at an abatement objective also satisfy the requirements of prevention for those regions of the river basin under surveillance [3, 4].

Thus, the study of general application of systems analysis techniques to design of water quality surveillance systems reported in [5] focuses on in-stream surveillance. It addresses the question of setting up in-stream water quality surveillance systems throughout the country, in accordance with the earlier version of the Federal Water Pollution Control Act [9]. To insure compatibility of individual systems developed by various federal, state and regional agencies, systems analysis techniques are adapted to the design of the surveillance systems.

The resulting systems analysis framework is summarized in Figure 1 (Figure 7 from [5]). The figure presents an integrated analysis of all the pertinent considerations inherent to the establishment of an in-stream water quality surveillance system. The analysis is compatible with any specific geographic area of interest.

The logic represented in Figure 1 can be divided into two stages of system design development. The first stage comprises those activities that analyze the relationship between the surveillance system and the natural system to be monitored. This preliminary design stage (shown in Figure 1 within the broken line) deals only with the establishment of water quality sampling on the basis of scientific and social considerations. The second, or final, design stage is composed of those activities that are aimed at the selection of the "best" realization of the preliminary design. The practical considerations of engineering, legal constraints, cost, reliability, and existing surveillance are used during the final design stage, to select a preferred implementation of the surveillance system.

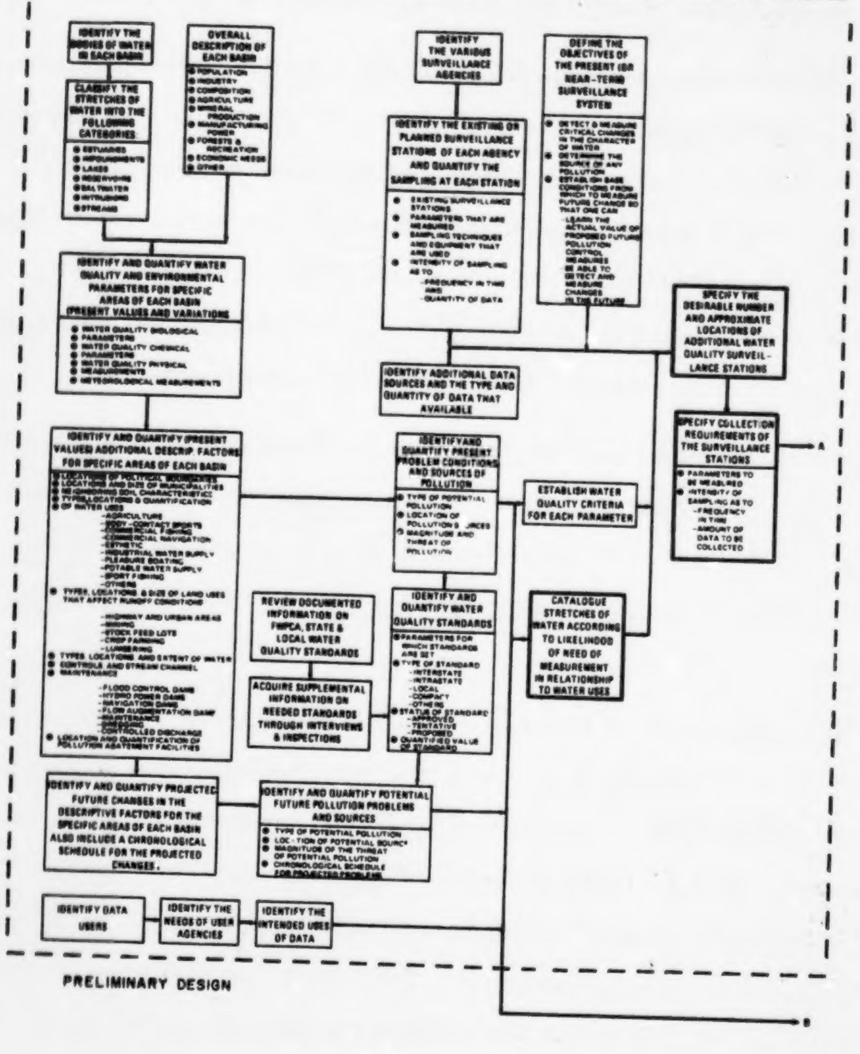

IDENTIFY THE BODIES OF WATER IN EACH BASIN
CLASSIFY THE STRETCHES OF WATER INTO THE FOLLOWING CATEGORIES
ESTUARIES
IMPOUNDMENTS
LAKES
RESERVOIRS
SALTWATER
INTRUSIONS
STREAMS
OVERALL DESCRIPTION OF EACH BASIN
POPULATION
INDUSTRY
COMPOSITION
AGRICULTURE
MINERAL PRODUCTION
MANUFACTURING POWER
FORESTS & RECREATION
ECONOMIC NEEDS
OTHER
IDENTIFY AND QUANTIFY WATER QUALITY AND ENVIRONMENTAL PARAMETERS FOR SPECIFIC AREAS OF EACH BASIN (PRESENT VALUES AND VARIATIONS
WATER QUALITY BIOLOGICAL PARAMETERS
WATER QUALITY CHEMICAL PARAMETERS
WATER QUALITY PHYSICAL MEASUREMENTS
METEOROLOGICAL MEASUREMENTS
IDENTIFY AND QUANTIFY (PRESENT VALUES) ADDITIONAL DESCRIP. FACTORS FOR SPECIFIC AREAS OF EACH BASIN
LOCATIONS OF POLITICAL BOUNDARIES
LOCATIONS AND SIZE OF MUNICIPALITIES
NEIGHBORING SOIL CHARACTERISTICS
TYPES, LOCATIONS & QUANTIFICATION OF WATER USES
-AGRICULTURE
-BODY-CONTACT SPORTS
-COMMERCIAL FISHING
-COMMERCIAL NAVIGATION
-ESTHETIC
-INDUSTRIAL WATER SUPPLY
-PLEASURE BOATING
-POTABLE WATER SUPPLY
-SPORT FISHING
-OTHERS
TYPES, LOCATIONS & SIZE OF LAND USES THAT AFFECT RUNOFF CONDITIONS
-HIGHWAY AND URBAN AREAS
-MINING
-STOCK FEED LOTS
-CROP FARMING
-LUMBERING
TYPES, LOCATIONS AND EXTENT OF WATER CONTROLS AND STREAM CHANNEL MAINTENANCE
-FLOOD CONTROL DAMS
-HYDRO POWER DAMS
-NAVIGATION DAMS
-FLOW AUGMENTATION DAMS
-MAINTENANCE
-DREDGING
-CONTROLLED DISCHARGE
LOCATION AND QUANTIFICATION OF POLLUTION ABATEMENT FACILITIES
IDENTIFY AND QUANTIFY PROJECTED FUTURE CHANGES IN THE DESCRIPTIVE FACTORS FOR THE SPECIFIC AREAS OF EACH BASIN ALSO INCLUDE A CHRONOLOGICAL SCHEDULE FOR THE PROJECTED CHANGES.
IDENTIFY DATA USERS
IDENTIFY THE NEEDS OF USER AGENCIES
IDENTIFY THE INTENDED USES OF DATA
IDENTIFY THE VARIOUS SURVEILLANCE AGENCIES
IDENTIFY THE EXISTING OR PLANNED SURVEILLANCE STATIONS OF EACH AGENCY AND QUANTIFY THE SAMPLING AT EACH STATION
EXISTING SURVEILLANCE STATIONS
PARAMETERS THAT ARE MEASURED
SAMPLING TECHNIQUES AND EQUIPMENT THAT ARE USED
INTENSITY OF SAMPLING AS TO
-FREQUENCY IN TIME AND
-QUANTITY OF DATA
DEFINE THE OBJECTIVES OF THE PRESENT (OR NEAR-TERM SURVEILLANCE SYSTEM
DETECT & MEASURE CRITICAL CHANGES IN THE CHARACTER OF WATER
DETERMINE THE SOURCE OF ANY POLLUTION
ESTABLISH BASE CONDITIONS FROM WHICH TO MEASURE FUTURE CHANGE SO THAT ONE CAN
-LEARN THE ACTUAL VALUE OF PROPOSED FUTURE POLLUTION CONTROL MEASURES
-BE ABLE TO DETECT AND MEASURE CHANGES IN THE FUTURE
IDENTIFY ADDITIONAL DATA SOURCES AND THE TYPE AND QUANTITY OF DATA THAT AVAILABLE
SPECIFY THE DESIRABLE NUMBER AND APPROXIMATE LOCATIONS OF ADDITIONAL WATER QUALITY SURVEIL-LANCE STATIONS
SPECIFY COLLECTION REQUIREMENTS OF THE SURVEILLANCE STATIONS
PARAMETERS TO BE MEASURED
INTENSITY OF SAMPLING AS TO
-FREQUENCY IN TIME
-AMOUNT OF DATA TO BE COLLECTED
A
IDENTIFY AND QUANTIFY PRESENT PROBLEM CONDITIONS AND SOURCES OF POLLUTION
TYPE OF POTENTIAL POLLUTION
LOCATION OF POLLUTION SOURCES
MAGNITUDE AND THREAT OF POLLUTION
ESTABLISH WATER QUALITY CRITERIA FOR EACH PARAMETER
REVIEW DOCUMENTED INFORMATION ON FWPCA, STATE & LOCAL WATER QUALITY STANDARDS
ACQUIRE SUPPLEMENTAL INFORMATION ON NEEDED STANDARDS THROUGH INTERVIEWS & INSPECTIONS
IDENTIFY AND QUANTIFY WATER QUALITY STANDARDS
PARAMETERS FOR WHICH STANDARDS ARE SET
TYPE OF STANDARD
-INTERSTATE
-INTRASTATE
-LOCAL
-COMPANY
-OTHERS
STATUS OF STANDARD
-APPROVED
-TENTATIVE
-PROPOSED
QUANTIFIED VALUE OF STANDARD
CATALOGUE STRETCHES OF WATER ACCORDING TO LIKELIHOOD OF NEED OF MEASUREMENT IN RELATIONSHIP TO WATER USES
IDENTIFY AND QUANTIFY POTENTIAL FUTURE POLLUTION PROBLEMS AND SOURCES
TYPE OF POTENTIAL POLLUTION
LOCATION OF POTENTIAL SOURCE
MAGNITUDE OF THE THREAT OF POTENTIAL POLLUTION
CHRONOLOGICAL SCHEDULE FOR PROJECTED PROBLEMS
PRELIMINARY DESIGN
B

Figure 1. General Systems Analysis Framework (Sheet 1 of 2)

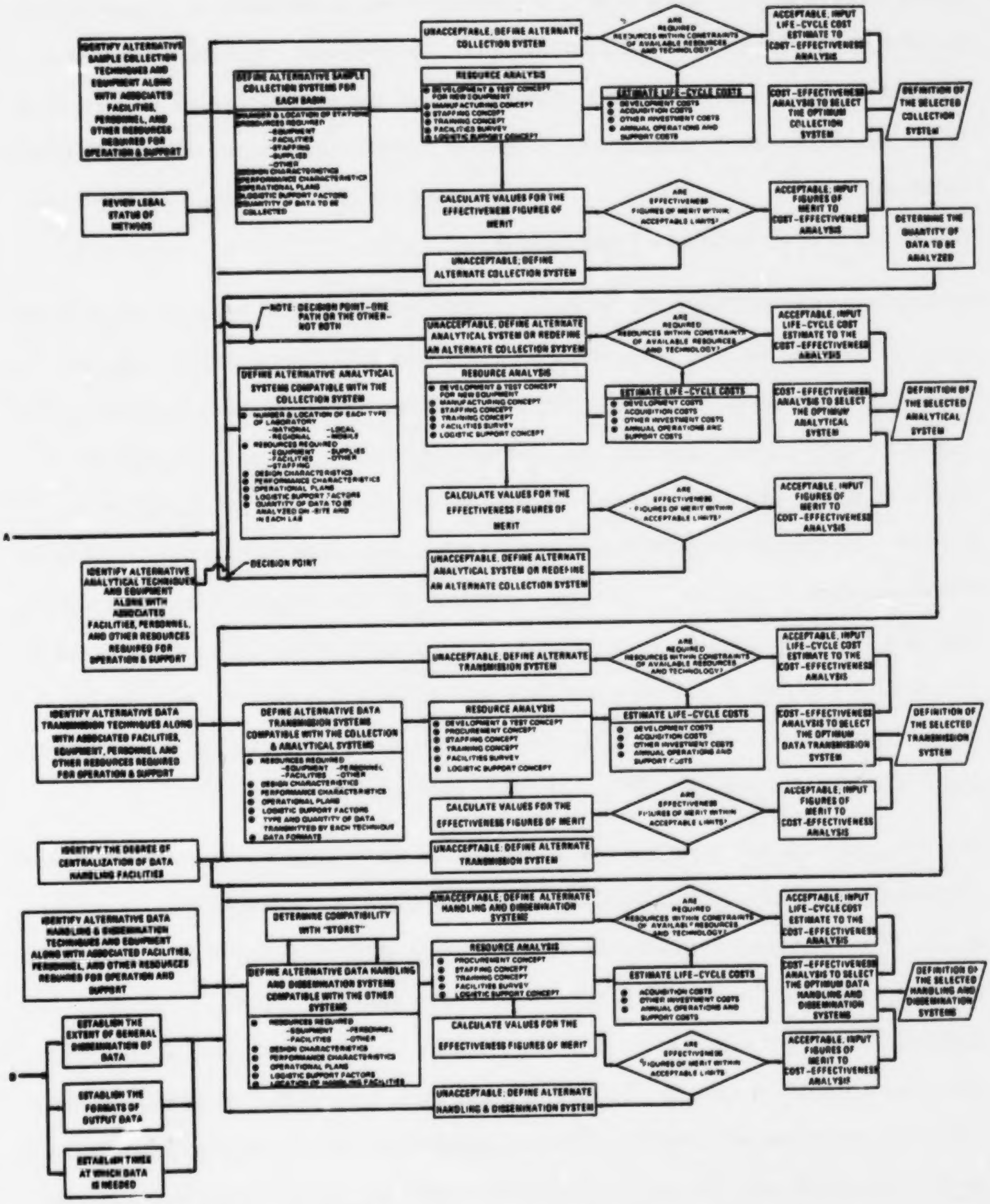

IDENTIFY ALTERNATIVE SAMPLE COLLECTION TECHNIQUES AND EQUIPMENT ALONG WITH ASSOCIATED FACILITIES, PERSONNEL, AND OTHER RESOURCES REQUIRED FOR OPERATION & SUPPORT
REVIEW LEGAL STATUS OF METHODS
DEFINE ALTERNATIVE SAMPLE COLLECTION SYSTEMS FOR EACH BASIN
NUMBER & LOCATION OF STATIONS
RESOURCES REQUIRED
-EQUIPMENT
-FACILITIES
-STAFFING
-SUPPLIES
-OTHER
DESIGN CHARACTERISTICS
PERFORMANCE CHARACTERISTICS
OPERATIONAL PLANS
LOGISTIC SUPPORT FACTORS
QUANTITY OF DATA TO BE COLLECTED
UNACCEPTABLE, DEFINE ALTERNATE COLLECTION SYSTEM
RESOURCE ANALYSIS
DEVELOPMENT & TEST CONCEPT FOR NEW EQUIPMENT
MANUFACTURING CONCEPT
STAFFING CONCEPT
TRAINING CONCEPT
FACILITIES SURVEY
LOGISTIC SUPPORT CONCEPT
ARE REQUIRED RESOURCES WITHIN CONSTRAINTS OF AVAILABLE RESOURCES AND TECHNOLOGY?
ESTIMATE LIFE-CYCLE COSTS
DEVELOPMENT COSTS
ACQUISITION COSTS
OTHER INVESTMENT COSTS
ANNUAL OPERATIONS AND SUPPORT COSTS
ACCEPTABLE; INPUT LIFE-CYCLE COST ESTIMATE TO COST-EFFECTIVENESS ANALYSIS
COST-EFFECTIVENESS ANALYSIS TO SELECT THE OPTIMUM COLLECTION SYSTEM
DEFINITION OF THE SELECTED COLLECTION SYSTEM
CALCULATE VALUES FOR THE EFFECTIVENESS FIGURES OF MERIT
ARE EFFECTIVENESS FIGURES OF MERIT WITHIN ACCEPTABLE LIMITS?
ACCEPTABLE; INPUT FIGURES OF MERIT TO COST-EFFECTIVENESS ANALYSIS
DETERMINE THE QUANTITY OF DATA TO BE ANALYZED
UNACCEPTABLE; DEFINE ALTERNATE COLLECTION SYSTEM
NOTE: DECISION POINT-ONE PATH OR THE OTHER-NOT BOTH
UNACCEPTABLE, DEFINE ALTERNATE ANALYTICAL SYSTEM OR REDEFINE AN ALTERNATE COLLECTION SYSYEM
ACCEPTABLE, INPUT LIFE-CYCLE COST ESTIMATE TO THE COST-EFFECTIVENESS ANALYSIS
DEFINE ALTERNATIVE ANALYTICAL SYSTEMS COMPATIBLE WITH THE COLLECTION SYSTEM
NUMBER & LOCATION OF EACH TYPE OF LABORATORY
-NATIONAL
-LOCAL
-REGIONAL
-MOBILE
RESOURCES REQUIRED
-EQUIPMENT
-SUPPLIES
-FACILITIES
-OTHER
-STAFFING
DESIGN CHARACTERISTICS
PERFORMANCE CHARACTERISTICS
OPERATIONAL PLANS
LOGISTIC SUPPORT FACTORS
QUANTITY OF DATA TO BE ANALYZED ON-SITE AND IN EACH LAB
RESOURCE ANALYSIS
DEVELOPMENT & TEST CONCEPT FOR NEW EQUIPMENT
MANUFACTURING CONCEPT
STAFFING CONCEPT
TRAINING CONCEPT
FACILITIES SURVEY
LOGISTIC SUPPORT CONCEPT
ESTIMATE LIFE-CYCLE COSTS
DEVELOPMENT COSTS
ACQUISITION COSTS
OTHER INVESTMENT COSTS
ANNUAL OPERATIONS AND SUPPORT COSTS
COST-EFFECTIVENESS ANALYSIS TO SELECT THE OPTIMUM ANALYTICAL SYSTEM
DEFINITION OF THE SELECTED ANALYTICAL SYSTEM
CALCULATE VALUES FOR THE EFFECTIVENESS FIGURES OF MERIT
ARE EFFECTIVENESS FIGURES OF MERIT WITHIN ACCEPTABLE LIMITS?
ACCEPTABLE, INPUT FIGURES OF MERIT TO COST-EFFECTIVENESS ANALYSIS
A
IDENTIFY ALTERNATIVE ANALYTICAL TECHNIQUES AND EQUIPMENT ALONG WITH ASSOCIATED FACILITIES, PERSONNEL, AND OTHER RESOURCES REQUIRED FOR OPERATION & SUPPORT
DECISION POINT
UNACCEPTABLE, DEFINE ALTERNATE ANALYTICAL SYSTEM OR REDEFINE AN ALTERNATE COLLECTION SYSTEM
UNACCEPTABLE, DEFINE ALTERNATE TRANSMISSION SYSTEM
ARE REQUIRED RESOURCES WITHIN CONSTRAINTS OF AVAILABLE RESOURCES AND TECHNOLOGY?
ACCEPTABLE, INPUT LIFE-CYCLE COST ESTIMATE TO THE COST-EFFECTIVENESS ANALYSIS
IDENTIFY ALTERNATIVE DATA TRANSMISSION TECHNIQUES ALONG WITH ASSOCIATED FACILITIES, EQUIPMENT, PERSONNEL AND OTHER RESOURCES REQUIRED FOR OPERATION & SUPPORT
DEFINE ALTERNATIVE DATA TRANSMISSION SYSTEMS COMPATIBLE WITH THE COLLECTION & ANALYTICAL SYSTEMS
RESOURCES REQUIRED
-EQUIPMENT
-PERSONNEL
-FACILITIES
-OTHER
DESIGN CHARACTERISTICS
PERFORMANCE CHARACTERISTICS
OPERATIONAL PLANS
LOGISTIC SUPPORT FACTORS
TYPE AND QUANTITY OF DATA TRANSMITTED BY EACH TECHNIQUE
DATA FORMATS
RESOURCE ANALYSIS
DEVELOPMENT & TEST CONCEPT
PROCUREMENT CONCEPT
STAFFING CONCEPT
TRAINING CONCEPT
FACILITIES SURVEY
LOGISTIC SUPPORT CONCEPT
ESTIMATE LIFE-CYCLE COSTS
DEVELOPMENT COSTS
ACQUISITION COSTS
OTHER INVESTMENT COSTS
ANNUAL OPERATIONS AND SUPPORT COSTS
COST-EFFECTIVENESS ANALYSIS TO SELECT THE OPTIMUM DATA TRANSMISSION SYSTEM
DEFINITION OF THE SELECTED TRANSMISSION SYSTEM
CALCULATE VALUES FOR THE EFFECTIVENESS FIGURES OF MERIT
ARE EFFECTIVENESS FIGURES OF MERIT WITHIN ACCEPTABLE LIMITS?
ACCEPTABLE, INPUT FIGURES OF MERIT TO COST-EFFECTIVENESS ANALYSIS
IDENTIFY THE DEGREE OF CENTRALIZATION OF DATA HANDLING FACILITIES
UNACCEPTABLE: DEFINE ALTERNATE TRANSMISSION SYSTEM
UNACCEPTABLE; DEFINE ALTERNATE HANDLING AND DISSEMINATION SYSTEMS
DETERMINE COMPATIBILITY WITH "STORET"
ARE REQUIRED RESOURCES WITHIN CONSTRAINTS OF AVAILABLE RESOURCES AND TECHNOLOGY?
ACCEPTABLE, INPUT LIFE-CYCLE COST ESTIMATE TO THE COST-EFFECTIVENESS ANALYSIS
IDENTIFY ALTERNATIVE DATA HANDLING & DISSEMINATION TECHNIQUES AND EQUIPMENT ALONG WITH ASSOCIATED FACILITIES, PERSONNEL, AND OTHER RESOURCES REQUIRED FOR OPERATION AND SUPPORT
DEFINE ALTERNATIVE DATA HANDLING AND DISSEMINATION SYSTEMS COMPATIBLE WITH THE OTHER SYSTEMS
RESOURCES REQUIRED
-EQUIPMENT
-PERSONNEL
-FACILITIES
-OTHER
DESIGN CHARACTERISTICS
PERFORMANCE CHARACTERISTICS
OPERATIONAL PLANS
LOGISTIC SUPPORT FACTORS
LOCATION OF HANDLING FACILITIES
RESOURCE ANALYSIS
PROCUREMENT CONCEPT
STAFFING CONCEPT
TRAINING CONCEPT
FACILITIES SURVEY
LOGISTIC SUPPORT CONCEPT
ESTIMATE LIFE-CYCLE COSTS
ACQUISITION COSTS
OTHER INVESTMENT COSTS
ANNUAL OPERATIONS AND SUPPORT COSTS
COST-EFFECTIVENESS ANALYSIS TO SELECT THE OPTIMUM DATA HANDLING AND DISSEMINATION SYSTEMS
DEFINITION OF THE SELECTED HANDLING AND DISSEMINATION SYSTEMS
CALCULATE VALUES FOR THE EFFECTIVENESS FIGURES OF MERIT
ARE EFFECTIVENESS FIGURES OF MERIT WITHIN ACCEPTABLE LIMITS
ACCEPTABLE, INPUT FIGURES OF MERIT TO COST-EFFECTIVENESS ANALYSIS
ESTABLISH THE EXTENT OF GENERAL DISSEMINATION OF DATA
B
ESTABLISH THE FORMATS OF OUTPUT DATA
ESTABLISH TIMES AT WHICH DATA IS NEEDED
UNACCEPTABLE: DEFINE ALTERNATE HANDLING & DISSEMINATION SYSTEM

Figure 1. General Systems Analysis Framework (Sheet 2 of 2)

A qualitative approach to the application of the general system design method is demonstrated in [5]. As a result, a number of recommendations are advanced to further development of the systems analysis methods. Among them is one suggesting that " . . . the tasks, functions, and interrelationships as identified in the systems analytical framework should be described in specific quantitative relationships . . . " and that " . . . a user handbook . . . should be developed to describe these techniques and extend their utility."

Several approaches to providing such quantitative relationships have been developed [3, 4, 6]. Each is based on a different theoretical foundation, but the results are, in many respects, comparable. The development presented in this report is a direct extension of one of these approaches [3] and, in conjunction with that work, provides a complete quantitative method for the design of instream water quality surveillance systems for abatement purposes according to the framework of Figure 1. Ward's approach [4] is somewhat less quantitative, but still provides a complete method for evaluating system designs within the framework presented in Figure 1. Moore's method [6], like the earlier Raytheon report [3], is confined to the preliminary design phase of system design. Each of these is discussed in the following paragraphs.

Ward's approach [4] discusses both prevention and abatement-type surveillance. The description here is confined to abatement since the present study is so confined. The approach calls for the location of surveillance stations at the critical quality point below each major area of pollution sources. The critical point is defined by comparison of a quantitative characterization of stream quality with the stream quality standards. No attempt is made to associate a numerical priority with each recommended location and no recognition is given to the possibility that the critical point will vary according to specific pollutant. An optimization theoretic approach developed by Vanderholm [10] is used in the selection of sampling frequency. A computerized simulation provides a number of random, artificial pollution events that are matched against candidate sampling schemes to select the best candidate on the basis of percentage detection. The distribution of event initiation is uniform in space and time, with deterministic event durations. Thus, while recognition is given to the existence of major point sources in selection of the spatial sampling scheme, the higher probability of violation events associated with these sources is ignored in determination of the temporal sampling scheme. In addition, the use of a uniform random distribution in the computation ignores the real physical processes that influence the temporal initiation and termination of a pollution event. Finally, it is noted that the selection of sampling is done on a reach by reach basis, without consideration of the possible influence of upstream reaches.

Another quantitative preliminary design method, based on estimation theory, has been studied by Moore [6]. His method makes use of the Kalman filter technique to provide estimates of the water quality, based on a current set of field observations and an a priori description of the natural system being monitored (a dynamic model). Figure 2 is a schematic representation of the filter method. A feature of the method is the indirect way in which the actual field data are used to produce the current estimate of the water quality. Roughly speaking, the current estimate is based on our projection of the current value from the previous estimate using the dynamic model, with a weighted correction for the difference between the projection and the current observed value. A decision on the existence of a violation is based on a comparison of the current estimate, not the observed value, with the water quality standards threshold. Since the estimated variance of the water quality estimate is also computed, it is possible to calculate the confidence in the decision. That is, it is possible to compute the probability that

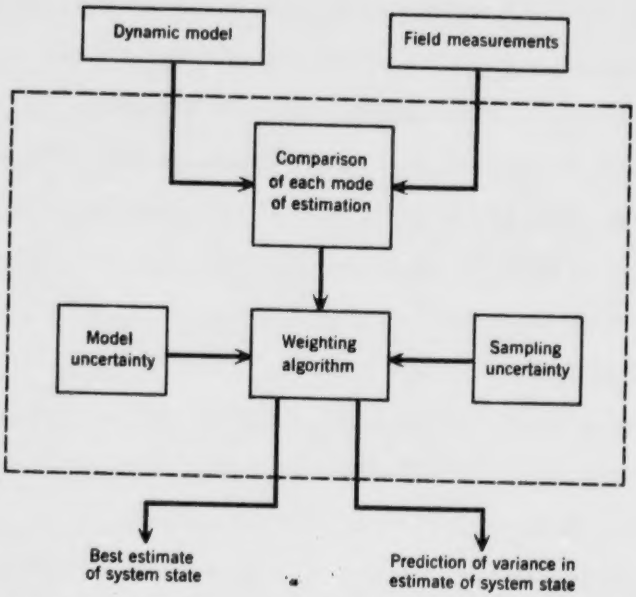

Dynamic model
Field measurements
Comparison of each mode of estimation
Model uncertainty
Weighting algorithm
Sampling uncertainty
Best estimate of system state
Prediction of variance in estimate of system state

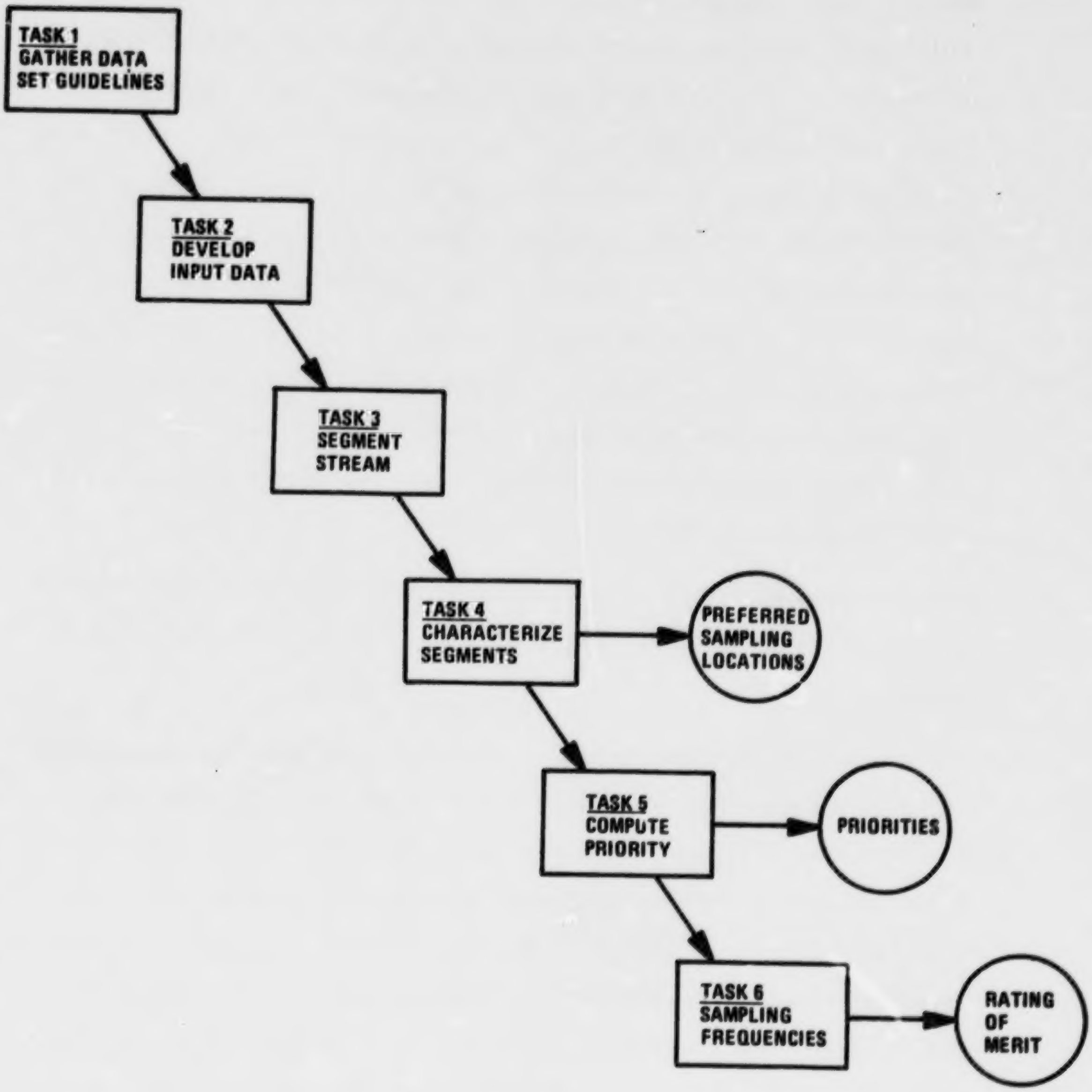
Figure 2. Schematic Representation of Filtering (from [6])

the decision is a correct one. Since Moore's method does not permit the computation of the probability of a violation existing at the time of observation, no estimate of the percent of violations detected can be obtained. For a given (arbitrary) candidate spatial distribution of monitoring, the temporal frequency can be optimized by selecting the minimum rate (i.e., minimum economic cost) that permits the achievement of a preselected confidence level. Thus, with Moore's method, it is possible to select a sampling scheme that is exceptionally good at detecting those events that exist when a sample is taken, but that may miss a very large number of violations. It should also be noted that the method does not immediately direct the user to locate stations at the points of highest probability of violation, although trial and error use should tend to produce a preference for these station locations. From a practical viewpoint, Moore's method is severely limited by the size of the covariance matrices and the associated computational costs necessary to analyze even simple river basins [6].

The method for preliminary system design developed by Raytheon [3] employs a decision theory approach that focuses attention on the event of interest, the water quality violation. Like Ward's approach, the optimization criterion is the maximization of the expected percent detection and it directs the designer to sample at the critical point. It is an improvement over Ward's method, in that it specifies a priority for each sampling station, based on the projected likelihood of violation. The temporal sampling frequency is determined analytically, rather than through use of a simulation approach. Selection of temporal sampling incorporates data on the expected behavior of the physical pollution processes by associating violations with the point sources and employing a Poisson distribution to describe the temporal variability. The method bases the violation detections directly on the observed data, an approach that is likely to be preferred in legal proceedings.

The essential features of Raytheon's quantitative preliminary design method [3] are detailed in the following paragraphs, since it forms the foundation for the present study.

Application of the Raytheon approach, as summarized in the User Handbook of [3], calls for sequential performance of six basic tasks. The general task flow is summarized in Figure 3 (Figure G-1 from [3]). Each of these tasks corresponds to one or more of the functional blocks in the general systems analysis framework (Figure 1). In Task 1, the user is concerned with gathering necessary data, organizing information and determining certain guidelines for his particular application. Task 2 is devoted to the development of specific items of information that characterize the river basin. This is accomplished by manipulation of the data collected in Task 1. In Task 3, the user begins the actual preliminary design by establishing stream segments, stretches of the stream



TASK 1
GATHER DATA
SET GUIDELINES
TASK 2
DEVELOP
INPUT DATA
TASK 3
SEGMENT
STREAM
TASK 4
CHARACTERIZE
SEGMENTS
PREFERRED
SAMPLING
LOCATIONS
TASK 5
COMPUTE
PRIORITY
PRIORITIES
TASK 6
SAMPLING
FREQUENCIES
RATING
OF
MERIT

Figure 3. Handbook Task Flow Diagram (from [3])

that may be dealt with as uniform units. Using the Task 3 segmentation, a simple mathematical model is employed in Task 4 to project the behavior of the stream. The preferred sampling locations may then be identified with the critical points predicted by the model. Using other data from the model, the priority of observing each parameter of interest at the preferred location in each segment is computed in Task 5. Finally, Task 6 is concerned with the computation of a rating curve for the evaluation of sampling frequencies. It should be noted that a unique preferred frequency of sampling cannot be derived from this method until other factors, such as cost, are considered (as is the case in the present study).

One recommendation reported in [3] proposes that the mathematical models used in Task 4 for stream characterization be computerized. The computerization would benefit the user in two ways. First, the procedures for computation of stream quality described in [3] are laborious. Although every attempt is made to minimize tedious hand computation, the procedures still require detailed manual calculation. Thus, computerization would increase their utility. Second, by computerizing, the user may take advantage of existing computerized river basin models, such as the RIBAM model [7]. Use of these models will provide even better estimates of stream conditions than can be achieved by the manual computations of [3]. The characterization of stream quality using the computerized model is described later in this section.

Turning to establishment of segment priority in Task 5, the mathematical basis for priority is the probability of violation. Probability of violation (π_v) is (for a "Not to Exceed"-type standard):

$$\pi_v(x) = \Pr\left(C(x) > C_T\right) = \int_{C_T}^{\infty} p(C;x)\,dC \tag{1}$$

where x = location

C = concentration

C_T = water quality standards threshold value

Pr = probability

p = probability density function

It is argued in [3] that the maximum expected π_v is α, defined by:

$$\alpha = \frac{\bar{C} - C_T}{\sigma_c} \tag{2}$$

where $\bar{C}$ = the mean concentration at the critical point

σ_c = the standard deviation of the concentration at the critical point and the critical point is the point of maximum or minimum (worst case) concentration.

The initial segment priority is defined to be α.

As the system designer selects segments for the implementation of monitoring, it may be anticipated that priority of the remaining segments will be changed. Due to the existence of a strong point source, several neighboring segments may initially have high priority. Establishment of a station in any one of them may be expected to detect violations in all of the highly correlated segments, so that the remaining, unmonitored segments take on a relatively lower priority.

The Raytheon quantitative preliminary design method incorporates a means for re-evaluating segment priority as stations are selected for implementation. The so-called ultimate segment priority is computed by considering the inter-segment correlation in the evaluation of priority.

The measure of sampling frequency effectiveness used in Task 6 for evaluation of sampling frequency is defined as:

$$M = \frac{\text{Expected Number of Violations Detected at a Point}}{\text{Expected Number of Violations at that Point}} \tag{3}$$

An analytical expression for the evaluation of M is developed in [3], using an assumed Poisson distribution in a Markov process to describe the violation process. That is, a two-state violation process is defined by the water quality standards and the expected temporal variation of concentration, as shown in Figure 4. The two-state process is used because most in-stream water quality standards are of the simple threshold type [3]. The severity of the violation is, therefore, not of interest in system design. Statistically, such a process may be described by the average duration of each state, T_0 and T_1, where the subscript 0 indicates "no violation" and the subscript 1 indicates "violation". It is shown in [3] that the expected number of violations, n_v, can be expressed as:

$$n_v = 1/(T_0 + T_1) \tag{4}$$

It is also indicated in [3] that a good approximation for the number of violations detected, n_d, is:

$$n_d \approx \frac{T_0 T_1}{\Delta\left[T_0^2 - T_1^2\right]} \left[\exp\left(-\frac{\Delta}{T_0}\right) - \exp\left(-\frac{\Delta}{T_1}\right)\right] \tag{5}$$

in which Δ is the sampling interval. Combination of equation (4) with equation (5) yields the approximate form of M:

$$M(\Delta, T_0, T_1) \approx \frac{T_0}{\Delta} \left[\frac{\exp(-\Delta/T_0) - \exp(-\Delta/T_1)}{(T_0/T_1) - 1}\right] \tag{6}$$

Estimates of T_0 and T_1 are obtained in Task 6, using information supplied by the mathematical model and a knowledge of the variability of water quality. The

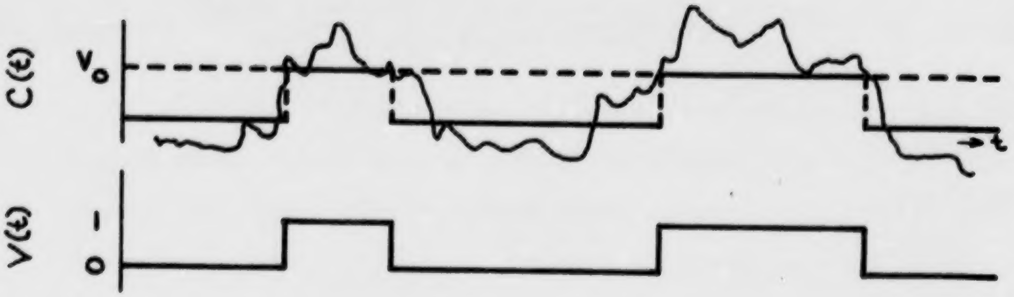


Figure 4. Conversion of Parameter Process into Violation Process (after [3])

result is an effectiveness rating curve, such as that shown in Figure 5. The system designer can use the rating curve in the selection of appropriate sampling frequencies, in conjunction with other factors, such as cost.

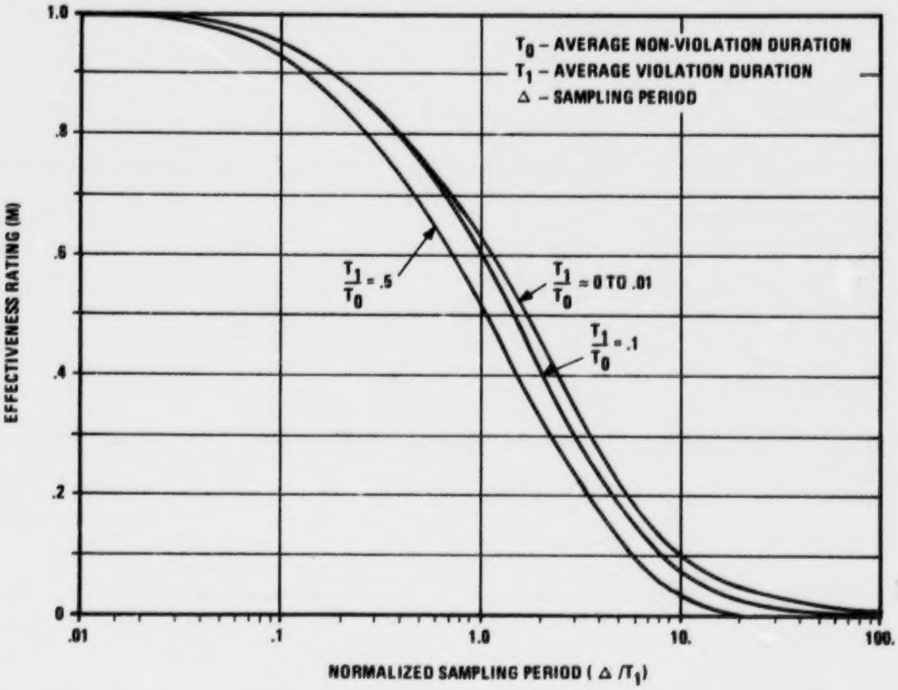


Figure 5. Temporal Effectiveness Rating as a Function of T_1, T_0 and Δ (from [3])

Implicit in the development of the quantitative methods reported in [3] is the concept of system duration. System duration is defined as that time over which the water quality surveillance system will maintain a fixed configuration of spatial and temporal sampling. All system design factors are average factors over the system duration. The need to monitor a segment of the river (π_V) is essentially the average need to monitor for the planned system duration. Similarly, the measure of time sampling effectiveness (M) is essentially the average effectiveness for the total span of the planned period of system operation.

For computational purposes, the system designer selects the system duration on the basis of constraints imposed by the objectives of the operating agency. If the surveillance system is intended solely to identify water quality violations during the low-flow period, then the system duration corresponds to that period. Typically, the system duration may be expected to range from about 3 months to about 5 years. The upper limit is defined by the time required to implement abatement actions of a magnitude sufficient to change the conditions for which the system is designed.

In fact, the design method, of necessity, assumes that conditions in the basin remain statistically constant throughout the system duration. As suggested above, implementation of abatement actions violates this assumption. Another violation of the assumption occurs when a polluter adjusts his operational schedule to avoid detection by the system. The surveillance system design method presented in this report and in [3] is not intended for conditions in which the polluters and the enforcers engage in "game playing". That is, there can be no feedback to the possible violator regarding the organization or operation of the surveillance system if the analysis is to hold.

Another concept essential to the quantitative design methods is the so called "macroscopic" concept. Under the "macroscopic" concept the spatial and temporal scales employed in the design methodology are restricted. The stream is treated as a one-dimensional flow, with depth and width entering only as they influence the values of coefficients and other natural characteristics, such as velocity. Point sources located in "close" proximity to each other are grouped and treated as a single source, based on a quantitative measure of closeness. Commensurate with the space scale, the time scale is restricted to very slow variations, those taking place over days. Computation of spatial factors is based on time-averaged inputs.

Therefore, a constraint on the quantitative methods of [3], as with several of the other methods reviewed in this section, is that it is restricted to the stream portions of the river basin. That is, the mathematical models used to characterize the water quality are one-dimensional models and are restricted to cases in which the concentration profiles along the depth and width can be considered uniform. Deep impoundments, such as reservoirs, estuaries and open coastal waters can not, in general, be included in the analysis, since they can rarely be described as one-dimensional. The quantitative methods are, however, entirely satisfactory for the greatest portion of the nation's river basins, that which can be considered one-dimensional to reasonable approximation.

In Section VII of this report, the relationship of each of the six tasks to the methods developed during this study is discussed in detail. The essential concepts of [3] have been preserved in the present development. In some cases, the details have been modified to accommodate the present needs.

As mentioned previously in this section, the manual computation of stream characterization is replaced in this report by a computerized mathematical model known as RIBAM (RIver BAsin Model). RIBAM was developed by Raytheon as part of the Beaver River Basin Modeling Project for the EPA and is documented in [7]. It is a modification and extension of the earlier DOSAG water quality model, prepared by the Texas Water Development Board to model two stream quality parameters, biochemical oxygen demand (BOD) and dissolved oxygen (DO) [11]. In developing RIBAM, the basic DOSAG model has been expanded to model as many as seventeen water quality parameters, plus four stream parameters. RIBAM is a steady-state, one-dimensional model, capable of adaptation to any river basin through the preparation of input data decks. Thus, it constitutes an equivalent replacement for the mathematical models used in [3].

The analytical approach used in RIBAM calls for representation of the river basin as a network consisting of four basic components:

1. Junctions—the confluence between two streams within the basin being modeled
2. Stretches—the length of river between junctions
3. Headwater stretches—the length of river from the headwater to the first junction with another stretch
4. Reaches—the subunits that comprise a stretch (either headwater or normal.

Reach boundaries are defined by any unique combination of the physical characteristics of the river basin, such as effluent sources, reaction rates or flow regimes. Thus, RIBAM reaches correspond to the stream segments defined in [3] and both terms are used interchangeably in this report.

The mathematical approach used in computation of the water quality parameters in the basin is a "piecewise continuous" approach, in which the parameter is assumed to behave according to a continuous differential equation throughout a reach. This approach may be used because the definition of a reach assumes that the important physical characteristics of the stream remain constant for the length of the reach.

The water quality parameters modeled in RIBAM are grouped into three categories:

1. conservative
2. non-conservative, non-coupled
3. non-conservative, coupled.

(See the Glossary, Appendix A, or [3] for discussions of these three terms.)

Each parameter within a given category is assumed to obey a general equation characteristic of that category. With the exception of the non-conservative, coupled category, the equations used in RIBAM are identical with those used in [3]. The non-conservative, coupled equations used in RIBAM are more sophisticated than those used in [3], since they consider coupling between more than two parameters at a time. Appendix A summarizes the mathematical details of RIBAM.

The top-level organization of the RIBAM computer programs, as they are used for river basin planning, is shown in Figure 6 (Figure 1 from [7]). The programs are written in FORTRAN IV and consist of a main program and twelve subroutines that perform the computations (see Figure 7).

The major restriction on RIBAM, as on the quantitative methods of [3], is in the consideration of deep impoundments. The mathematical models are so-called one-dimensional models and are restricted to cases in which the concentration profiles along the depth and width dimensions can be neglected. Clearly, deep

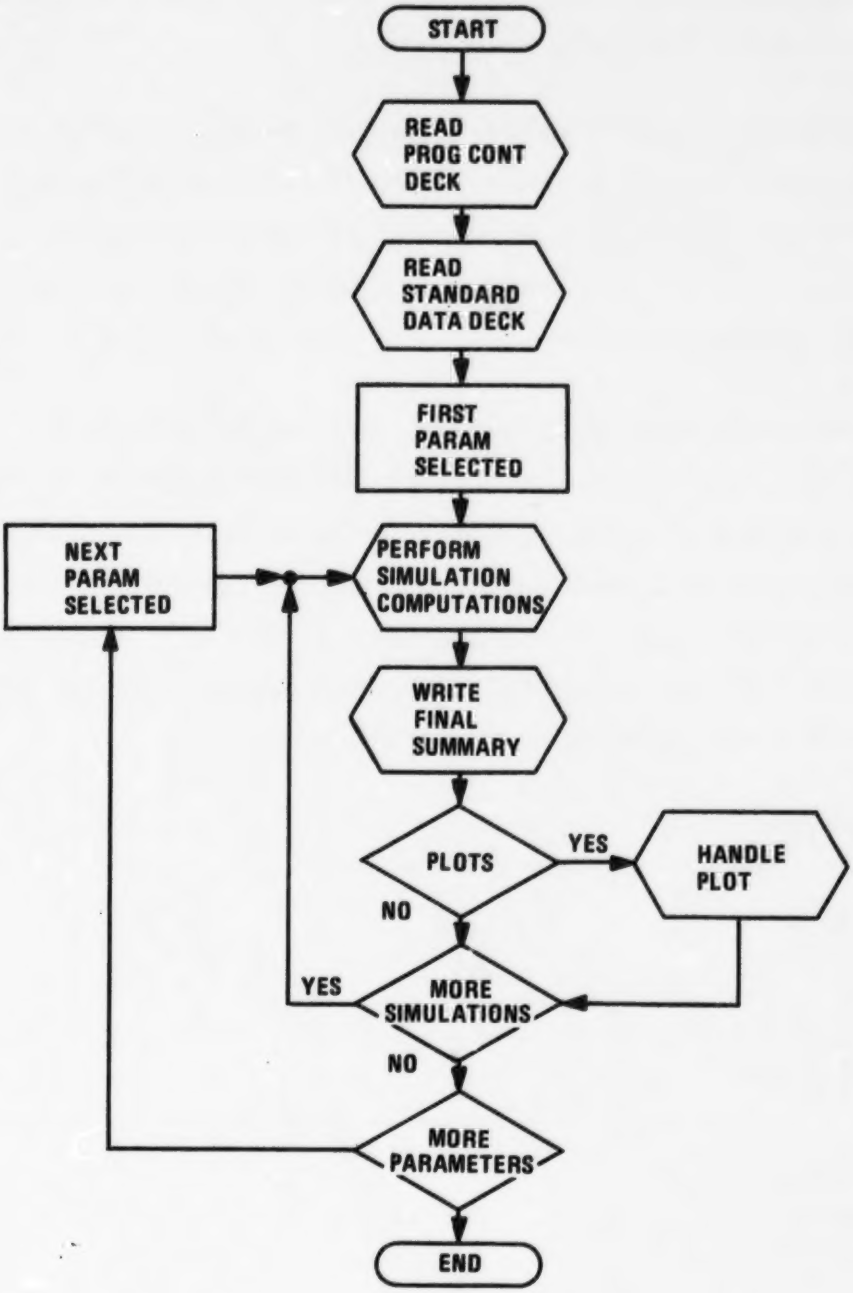

START
READ PROG CONT DECK
READ STANDARD DATA DECK
FIRST PARAM SELECTED
NEXT PARAM SELECTED
PERFORM SIMULATION COMPUTATIONS
WRITE FINAL SUMMARY
PLOTS
YES
HANDLE PLOT
NO
YES
MORE SIMULATIONS
NO
MORE PARAMETERS
END

Figure 6. RIBAM Top-Level Flow Chart (from [7])

impoundments such as deep reservoirs violate these conditions, because of the vertical stratification typical of such reservoirs.

Other restrictions are related primarily to computer storage limitations. They are summarized in Table 2. Another restriction is that the reaction rates of coupled parameters may not be equal, since that violates the mathematical assumptions of the model. (Intermediate forms are decaying as rapidly as they are created, if two or more coupled reaction rates are taken as equal.)

As used in the present study, the RIBAM model has been slightly modified. These modifications are discussed in detail in Section VII and Appendix E. In summary, the plotting subroutine CPLOT has been deleted and all written output has been eliminated. The main RIBAM program has been truncated and merged with a subroutine of the design methods programming. It is assumed that the systems designer will use the full RIBAM model for calibration purposes, prior to use of the Standard Data Decks for system design purposes.

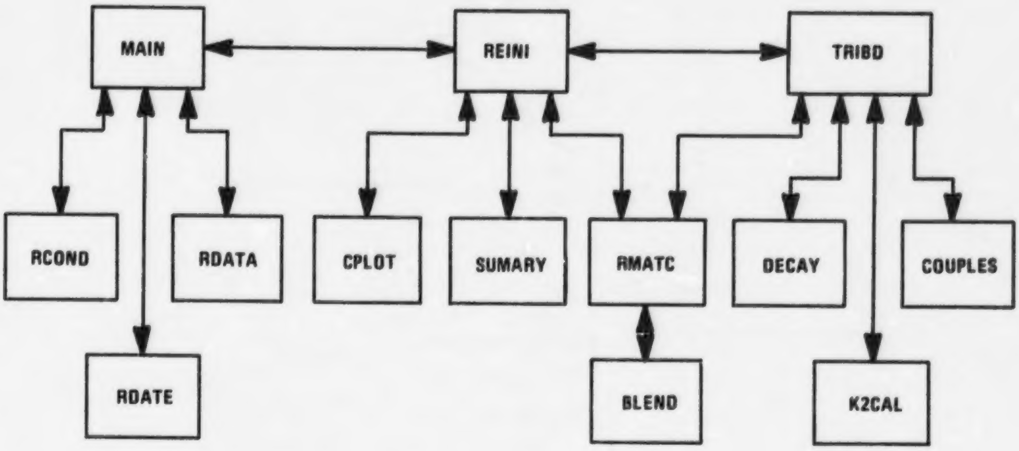


Figure 7. RIBAM Program Element Relationship (from [7])

Table 2. LIMITATIONS ON RIBAM (from [7])

Quantity	Maximum number
Headwater stretches	10
Junctions	10
Reaches	40
Stretches (including headwater stretches)	20
Reaches per stretch	20
Sequential simulations of each parameter using sensitivity analysis options	5

SECTION V

STUDY OBJECTIVE AND APPROACH

As a direct continuation of the studies discussed in Section IV, the objectives of this report and the approach taken are strongly related to those of its predecessors. In this section, the objectives of the present study are presented and related to the previous studies. A description of the basic approach taken in achieving the study objectives is then given and discussed in the perspective of the related studies.

STUDY OBJECTIVES

The objectives of the study are: 1) the augmentation of the existing quantitative procedure for preliminary design of water quality surveillance systems [3] with a means for including cost and effectiveness in the design process, and 2) the development of methods for utilizing computerized river basin models [7] to reduce the labor involved in system design. Implicit in the second objective is the general application of computerization to handle the detailed evaluation of candidate system designs.

Thus, the scope of the study is expanded from that of [3] to include both the preliminary design stage and nearly all of the final design stage (see Figure 1). Consideration of cost, reliability, maintenance and other aspects of real systems had been specifically excluded from [3]. In expanding the scope to include such factors, attention is focused on the collection and analysis subsystems diagrammed in Figure 1. Attention is focused on these two subsystems, because they appear most in need of treatment at this time. The other two subsystems, data transmission and data dissemination, are less dependent on a knowledge of the problems of water quality monitoring and more amenable to previously available engineering approaches.

Addition of a quantitative cost-effectiveness methodology to the existing procedures provides a "start-to-finish" numerical design capability for river basin surveillance system design. The use of such a design procedure assures uniformity in the results of monitoring system designs for the wide variety of river basins requiring surveillance. It standardizes approaches taken by the numerous responsible agencies and, thereby, promotes the correlation of information. It will support the application of legal action by assuring the defensibility of the monitoring approach. Finally, it allows management of system implementation based on quantitative judgments, rather than qualitative ones, in cases where constraints do not permit establishment of stations in every reach of the basin.

With the experience of demonstrating the preliminary design procedures on the Wabash River Basin, it became apparent that a computerized approach would simplify the application of the methods and greatly reduce the chance for careless errors. In addition, it was recognized that the analysis of system effectiveness would require extensive, detailed computations of system survivability, availability and capability, in which the effect of each individual component of the system would have to be considered.

With the development of a number of computerized river basin water quality models, for example [7], it became possible to consider using the existing basin models to automatically provide information obtained previously through tedious manual computation in [3]. By carefully merging these models with other computer programs designed to provide the system designer with an evaluation of the candidate system, the major portion of the design process could be automated.

This would leave the designer free to consider more important aspects of the design process than how to perform the massive computations.

STUDY APPROACH

Because the study is so closely tied to the previous work [3], the number of technical approaches considered was constrained to those compatible with the existing preliminary design methods. The basic assumptions made in the development of the preliminary design methods were carried over into the present study intact. These included the concept of system duration and the so-called "macroscopic" concept, in addition to the assumption that the need to monitor is related to the relative probability of violation. As before, attention is confined by the "macroscopic" concept to the "one-dimensional" portions of the river basin and the surveillance system is assumed to have the abatement objective.

However, it was recognized that automation of the preliminary design computations might require that some conceptual modifications be made. Provision was made to reconsider those aspects and to amend the design methods as appropriate. The results of the amendment process are described in Section VII.

The study approach called, first, for the theoretical development of the cost-effectiveness model. From the outset, it was recognized that the data available to the system designer for evaluation of cost-effectiveness would be minimal. The approach was to deal with the problem at a level where the suppliers of equipment and instrumentation might reasonably be required to produce the necessary data.

The cost-effectiveness model could then be merged with the preliminary design methodology to produce a consistent "start-to-finish" design method. A major aspect of the merger was the selection of optimum interaction points between the designer and what was to become an automated process. Another aspect of the merger was the optimization of basin model usage to minimize the necessity for repeated simulations of the river.

The design methodology could then be flow-charted and computerized. By careful development of the design logic, it was the intent that the system design programs be capable of being run on the same machines capable of handling the river basin models. For maximum compatibility, program coding was done consistent with the existing basin models in FORTRAN IV. Throughout the program development process, modular testing using artificial data was performed to verify the program coding.

In conjunction with the EPA, the Beaver River Basin was selected for demonstration of the design methodology. An important aspect of the demonstration activity was the feedback provided to update the methods.

In the next section, the theoretical development of the cost-effectiveness methods is presented.

SECTION VI

DEVELOPMENT OF COST-EFFECTIVENESS METHODS

The objective of this section is the development of methods for examining the cost-effectiveness of alternative approaches to water quality surveillance in a river basin. The discussion is, in general, confined to those portions of the methodology that are unique to the water quality surveillance system design process. No attempt is made to provide a text in engineering economics, cost accountancy, or reliability and maintainability. When necessary, individual topics from these disciplines, and others, are included for completeness. For detailed examinations of these fields of engineering, the reader is directed to their literature. In particular, [12], [13], [14], [15] and [16] have proven useful during the development of the cost-effectiveness methods described in this section.

SUMMARY OF COST-EFFECTIVENESS METHODS

Analysis of surveillance system cost-effectiveness requires the separate estimation of the system cost for the planned system duration and the expected effectiveness of the system over that time period. Effectiveness of water quality surveillance systems is defined as the expected percentage of the violations which occur throughout the basin during the system duration that are detected by the system. Cost analysis is conducted on the basis of an organizational framework incorporating both the system means that perform the in-line surveillance functions and the facilities that support those means. Costs are estimated for each system component in four areas:

- acquisition
- operation

- maintenance
- value on completion of system use.

Effectiveness is a function of:

- location
- sampling rate
- maintenance pattern
- availability
- survivability
- capability

of the individual system elements that perform the monitoring function.

These, in turn, are functions of the configuration and characteristics of the means incorporated in each system element. The estimation of system effectiveness is conducted within the framework of a functional analysis that specifies the role of each means in monitoring a specific site for a specific parameter.

INITIAL CONCEPTS OF COST EFFECTIVENESS

The objective of cost-effectiveness analysis is the selection of the "best" water quality surveillance system for a given river basin. The concept of the "best" system is explored here, along with the overall approach taken in selecting the "best" system.

A given configuration of means for accomplishing river basin surveillance may be evaluated on the basis of its ability to perform, relative to some ideal (the effectiveness of the configuration), and its total economic cost.

The word "means" is used throughout this report to indicate a way of performing a function necessary to the production of water quality data. A "means" may be a completely automated device, an entirely manual technique, or some combination of manual and automated equipments. The context should be sufficient to resolve any confusion between this usage of the word "means" and the plural form of the arithmetic average (the mean value).

One way to compare alternative system configurations is to consider only those alternatives that are specifically designed to achieve a single, unique level of effectiveness. Under these circumstances, the selected level of effectiveness will clearly meet minimum acceptance requirements, since it would be useless to design a system that did not. The choice of "best" configuration then resolves itself to identifying the minimum cost configuration (see Figure 8).

Another approach is to consider only those alternatives specifically designed to a single, unique expected cost. Once again, because the cost is selected a priori, it is certain to fall below any maximum acceptance level. The "best" configuration in this case is the one with the greatest effectiveness (see Figure 9).

Neither of these two approaches assures that both minimum effectiveness and maximum cost constraints will be met by the alternative selected. For example, all those alternatives considered that satisfy the fixed effectiveness criterion may be too costly (see Figure 10). For a fixed effectiveness, it may be very difficult to bring cost within acceptable limits.

A further difficulty with these two approaches lies in the design of systems to meet specific fixed criteria, either effectiveness or cost. It is felt that excessive effort may easily be expended in attempting to formulate alternate configurations of water quality surveillance systems that meet one or the other of these requirements. The difficulty may become particularly apparent when external constraints, such as maximum use of existing facilities, are imposed on the selection process.

Thus, the method used in evaluating alternative system configurations must be capable of comparing candidates for both cost and effectiveness, simultaneously. In addition, it must be capable of eliminating those candidates that either fail to achieve minimum effectiveness criteria or exceed maximum cost limits.

The use of the cost-effectiveness ratio as the measure of the proposed candidates satisfies the foregoing requirements on the method of evaluation. Since neither cost nor effectiveness is fixed initially, maximum flexibility is permitted in satisfying externally imposed constraints on system design. Candidates may be eliminated prior to computation of the cost-effectiveness ratio, should either cost or effectiveness be individually unacceptable. Of those alternatives that meet minimum acceptance standards, the "best" system is the candidate with minimum cost per unit effectiveness, in the acceptable region (see Figure 11).

Thus, the measure of goodness applied to an alternative configuration is the cost-effectiveness ratio (Γ):

$$\begin{aligned}\text{Cost-Effectiveness} &= \Gamma \\ &= \frac{\text{Total System Cost}}{\text{Total System Effectiveness}} \\ &= \frac{K_{sys}}{E_{sys}} \qquad (7)\end{aligned}$$

It should be apparent from the foregoing that the approach taken in determining the "best" configuration is a suboptimization approach. No attempt is made to determine the universally optimum configuration. The emphasis is placed on identifying the "best" of those alternatives considered, which may constitute a small sub-set of all possible alternatives. The cost-effectiveness method does not automatically result in synthesis of the "best" system. The system designer

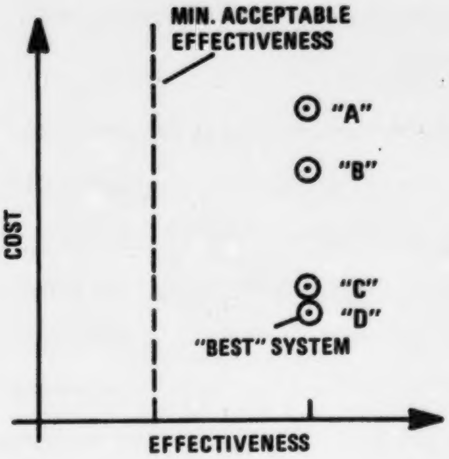

MIN. ACCEPTABLE EFFECTIVENESS
"A"
"B"
"C"
"D"
"BEST" SYSTEM
COST
EFFECTIVENESS

Figure 8. C-E Trade-off for Fixed Effectiveness

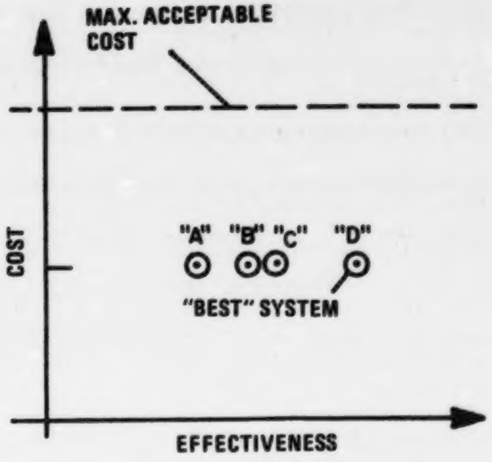

MAX. ACCEPTABLE COST
"A"
"B"
"C"
"D"
"BEST" SYSTEM
COST
EFFECTIVENESS

Figure 9. C-E Trade-off for Fixed Cost

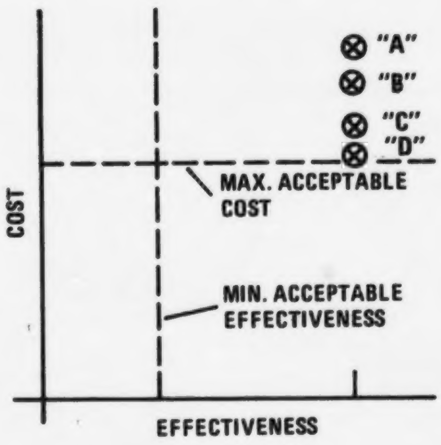

"A"
"B"
"C"
"D"
MAX. ACCEPTABLE COST
MIN. ACCEPTABLE EFFECTIVENESS
COST
EFFECTIVENESS

Figure 10. Unacceptable Result of Fixed Effectiveness Trade-off

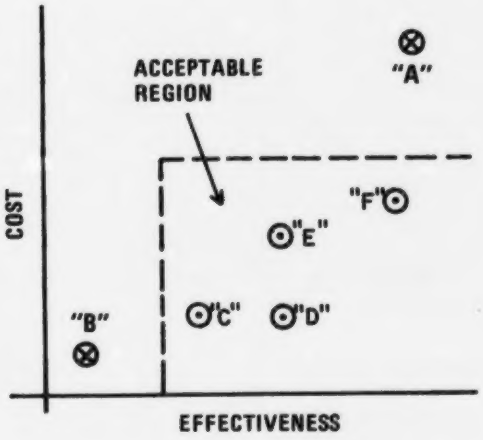

ACCEPTABLE REGION
"A"
"F"
"E"
"B"
"C"
"D"
COST
EFFECTIVENESS

Figure 11. C-E Ratio Approach to Candidate Selection

⊙ = Acceptable ⊗ = Unacceptable

must first synthesize each candidate, then compare its cost-effectiveness with those of other candidates that he has synthesized.

The flow diagram in Figure 12 shows the steps required to synthesize and compare alternative system configurations. The system design process begins with selection of a preliminary set of water quality parameters of interest to the designer. Typically, the selection is made on the basis of the applicable stream quality standards and expected sub-standard conditions. Using the techniques previously developed [3], the river basin is then modeled for these parameters to establish a measure of the parameter-segment priorities, preferred locations for sampling and the shape of the temporal sampling effectiveness curve. Based on the parameter-segment priorities, the designer may select a preferred set of system elements to be implemented. Using this set, he then selects one or more candidate configurations for implementation of the system. The candidates may then be evaluated for cost, effectiveness and the cost-effectiveness ratio.

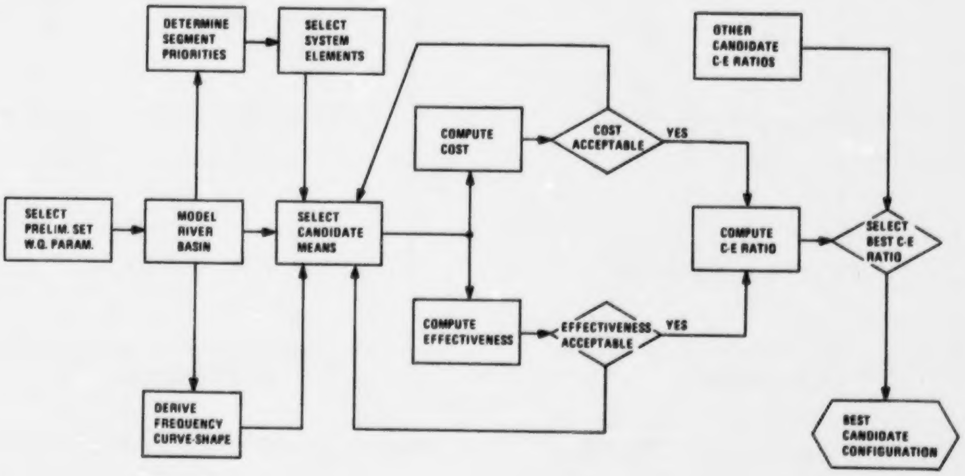

DETERMINE SEGMENT PRIORITIES
SELECT SYSTEM ELEMENTS
OTHER CANDIDATE C-E RATIOS
COMPUTE COST
COST ACCEPTABLE
YES
SELECT PRELIM. SET W.Q. PARAM.
MODEL RIVER BASIN
SELECT CANDIDATE MEANS
COMPUTE C-E RATIO
SELECT BEST C-E RATIO
COMPUTE EFFECTIVENESS
EFFECTIVENESS ACCEPTABLE
YES
DERIVE FREQUENCY CURVE-SHAPE
BEST CANDIDATE CONFIGURATION

Figure 12. System Design Flow Diagram

The total design process shown in Figure 12 is described in detail in Section VII—Design of Water Quality Surveillance Systems. In that section, the cost-effectiveness methods are merged with the preliminary design methods developed in [3] to form a unified, computerized design method.

In synthesizing the system configuration, the system designer should adopt a planning philosophy that includes contingency planning.

Such contingency planning may lead to the selection of back-up mechanisms that materially change the cost, performance or implementation pattern for the system. An example of this is the activation of a low sampling-rate, manual set of means to replace a high rate, automated system destroyed by a flood. It can be anticipated that material differences in both cost and performance between the manual and automatic means will exist. Another example is the need to temporarily divert manpower or equipment from a manned surveillance system to a higher priority activity not related to surveillance. In the second example, an entirely different set of system elements may be implemented for the duration of the resource diversion.

When contingency planning leads to selection of such materially different alternative system operating plans, the total system cost-effectiveness is computed on the basis of weighted average of the cost-effectiveness of the operating plans considered independently. The weighting function is the probability of activation of the operating plan, either normal or contingency. Thus, the total system cost-effectiveness of the n^{th} alternative system candidate is:

$$\Gamma_n = \sum_{\ell=1}^{L_n} \Gamma_\ell \, \Pr(\ell) \qquad (8)$$

where ℓ is the particular system operating plan under consideration for the candidate and L_n is the number of contingency plans associated with the n^{th} candidate. For example, a candidate system may call for sampling from a boat during normal conditions. As a contingency plan during high river stages when launching a boat might be dangerous, the intention may be to sample from bridges. The overall cost-effectivenss of the candidate would be the weighted sum of the separate cost-effectiveness of the two operating plans taken independently. The weighting would be the probabilities of normal and high-water stages.

ANALYSIS OF CANDIDATE SYSTEMS

Prior to a detailed development of the cost-effectiveness concepts, it is necessary to develop an analytical framework with which to describe each system candidate.

By choosing to deal with the design problem at a system level, recognition has been given to the need to consider the interrelationships that tie the system together, that make it a recognizable entity. One of the primary attributes of systems is their complexity. In particular, systems may be characterized by the multi-purpose utilization of individual system components (the means) [16].

Water quality surveillance systems may be described with either of two analytical frameworks. One is a functional framework related to the processes, equipments and personnel necessary to perform observations for a specific system element. The other is an organizational framework describing the operational relationships among the system means. For example, an atomic absorption spectrometer, (AA) may be used in a given surveillance system to detect heavy metals. If the heavy metals parameters are measured at a number of points in the basin, the single AA unit is functionally a component means in a number of system elements. Organizationally, the single AA unit is assigned to a single laboratory, along with other means, such as BOD incubators, that are associated with other system elements.

Each type of analytical framework has a unique use in the design methods. The organizational framework is most useful in the analysis and allocation of costs. The functional framework is used for analysis of system effectiveness, in which the technical or scientific worth of the system is assessed.

Organizational Analysis

The development of the system organizational framework is done in a straightforward way, using methods that should be familiar to anyone who works in a departmentalized organization.

For purposes of surveillance system design, two framework components are used: the means and the group. A means is the technique, apparatus, equipment and/or person by which a necessary function in the flow of information is performed. It is identical with the component of the same name used in functional analysis. A group is the operational unit, department, or laboratory to which several means or other lower-level groups are assigned. Thus, there may be several levels of groups, constituting a heirarchy. The highest level group is identical with the total surveillance system.

To illustrate the organizational analysis, take the example of the AA unit mentioned above (see Figure 13). The AA unit is a means in the acquisition and analysis of data for one or more system elements. It is located in a laboratory and supported by the facilities in the lab, including glassware, chemicals, water, electricity, and personnel. Thus, the AA is a component of the group called the

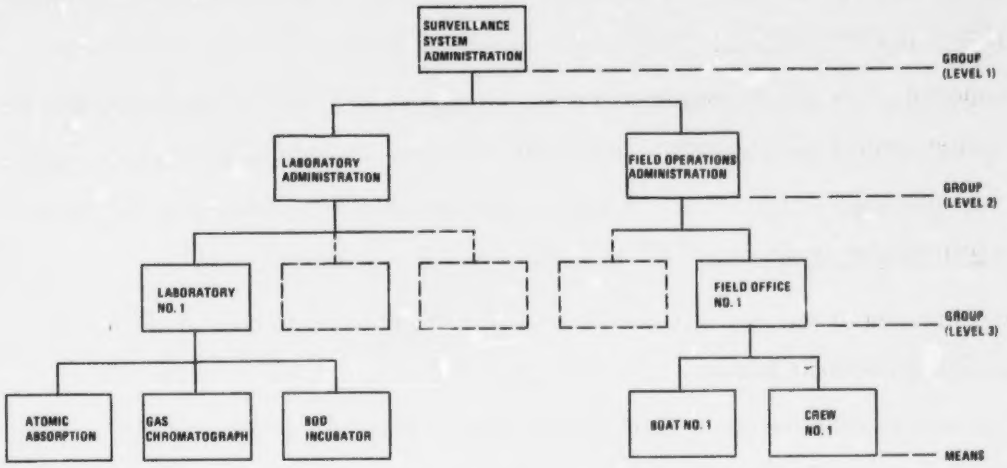

SURVEILLANCE SYSTEM ADMINISTRATION
GROUP (LEVEL 1)
LABORATORY ADMINISTRATION
FIELD OPERATIONS ADMINISTRATION
GROUP (LEVEL 2)
LABORATORY NO. 1
FIELD OFFICE NO. 1
GROUP (LEVEL 3)
ATOMIC ABSORPTION
GAS CHROMATOGRAPH
BOD INCUBATOR
BOAT NO. 1
CREW NO. 1
MEANS

Figure 13. Typical Organizational Framework

laboratory. In turn, the laboratory may be one of several such facilities supported and administered by another higher-level group. Finally, all such administrative groups are parts of the total surveillance system, the highest-level group.

The identification of component groups in the organizational structure is a matter of judgment on the part of the system designer. Because the organizational framework is used only in the cost analysis, the designer will generally prefer to use convenient cost units as the organizational group.

For purposes of the computerized analysis described in Section VII, it is necessary to assign identification numbers to the individual groups and means incorporated in the organizational framework. The highest level (i.e., system level) group is always assigned the identification number "1". All other groups may be numbered arbitrarily. The means are also numbered arbitrarily in a separate sequence; no special significance is attached to number "1" in the means sequence. The means numbers assigned in the organizational analysis must be identical with those described below for the functional analysis.

Functional Analysis

Development of the surveillance system functional framework is done on the basis of individual system elements. One of the basic assumptions of the surveillance system design method is that observations of a given parameter at a particular point in the stream are considered independently from all other observations. Thus, it is not necessary to prepare a single, system-wide functional analysis. The analyses are prepared separately for each parameter-segment pair to be monitored by the candidate system (a system element).

The objective of the functional analysis is the identification of all the alternative routes for each system element by which information on the presence or absence of a water quality violation travels from the sampling point in the stream to the recording point in the system.

At the highest level, there is only one path associated with each system element (the element path). That is, information enters the system element at only one point, the point of sample acquisition, and it leaves the system element at only one point, the point at which the data becomes available to users. The element path may include one or more serially connected means and two or more sub-paths.

In turn, sub-paths may include one or more serially connected means and two or more lower-level sub-paths. A sub-path always begins and terminates at a node, a branching point in an element, where information may take any of two or more parallel sub-paths. Sub-paths may be either normally active or normally standby. In the latter case, the standby sub-path is activated upon failure of the parallel sub-path that it backs-up.

It should be noted that, in the functional analysis, it is not necessary to explicitly identify the support facilities associated with a means, as is the case for organizational analysis. In functional analysis, only the means that participate directly in the flow of information are included in the analysis framework.

To illustrate and clarify the significance of each of these terms, consider the example in Figure 14. Each rectangle indicates an individual means. The solid lines connecting the means indicate the routes along which information flows in the system. Two system elements are shown in Figure 14; they correspond to monitoring of two different parameters in the same segment. They share several means, including the telemetry unit, the office telemetry/recorder, and the maintenance man who periodically collects the data from the back-up field recorders. The first system element (Element 1-1) has one element path consisting of one serial means and two sub-paths. The two sub-paths back up each-other and are both normally operating. Each sub-path has two serial means and no lower-level sub-paths. The second system element also has one element path consisting of one serial means and two sub-paths. In this case, one of the sub-paths is a stand-by sub-path, activated only on failure of the prime path.

The element paths, sub-paths and means are diagrammed in Figure 15. The letters correspond to those in the upper right-hand corners of the means symbols in Figure 14.

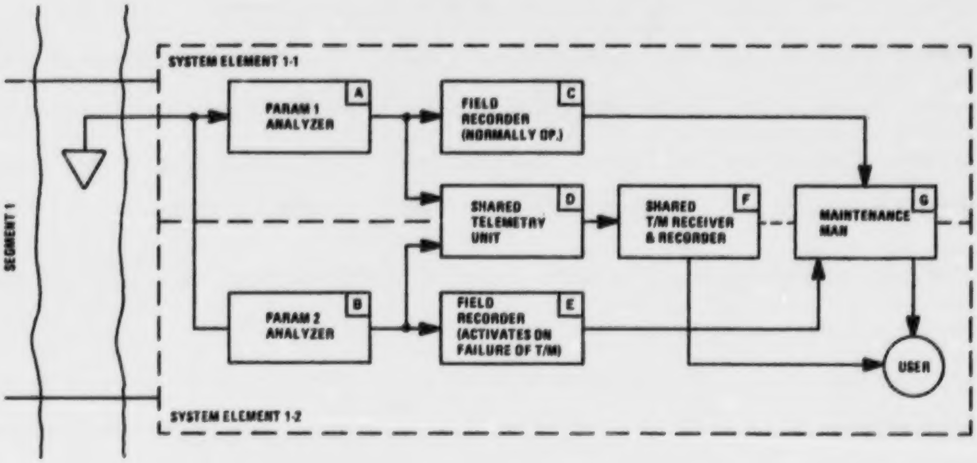

SYSTEM ELEMENT 1-1
SEGMENT 1
A
PARAM 1 ANALYZER
C
FIELD RECORDER (NORMALLY OP.)
D
SHARED TELEMETRY UNIT
F
SHARED T/M RECEIVER & RECORDER
G
MAINTENANCE MAN
B
PARAM 2 ANALYZER
E
FIELD RECORDER (ACTIVATES ON FAILURE OF T/M)
USER
SYSTEM ELEMENT 1-2

Figure 14. Typical Station Functional Structure

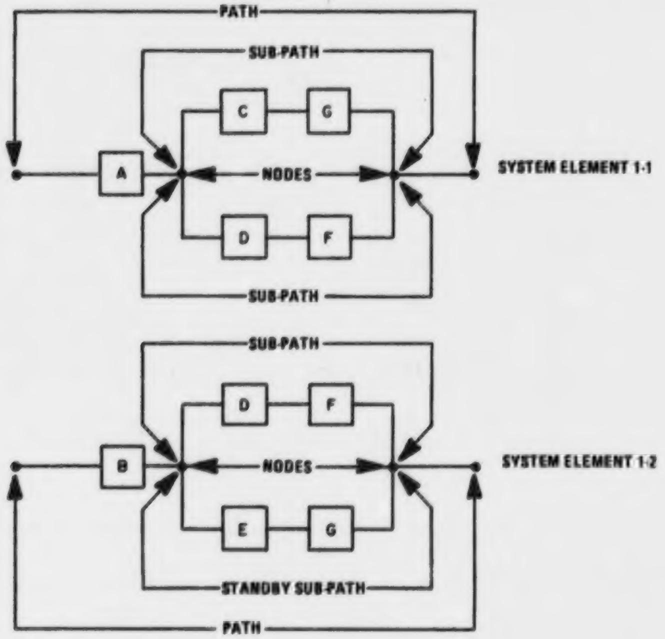

PATH
SUB-PATH
C
G
A
NODES
SYSTEM ELEMENT 1-1
D
F
SUB-PATH
SUB-PATH
D
F
B
NODES
SYSTEM ELEMENT 1-2
E
G
STANDBY SUB-PATH
PATH

Figure 15. Typical Functional Frameworks for Station Illustrated in Figure 14

As can be seen in Figure 16, a given system element may have several levels of paths and sub-paths. The main path in this example consists of two serial means H and M, and two first-level sub-paths. One of these first-level sub-paths consist of two serial means, P and N. The other consists of two serial means, I and J, and two second-level subpaths, each consisting of only one serial means (K and L, respectively).

The inherent complexity of a multi-segment, multi-parameter, multi-means, multi-path surveillance system can readily be understood from the simple illustrations just given. The definitions provide a framework by which to analyze the surveillance system into a manageable body of data that fully describe the system functioning.

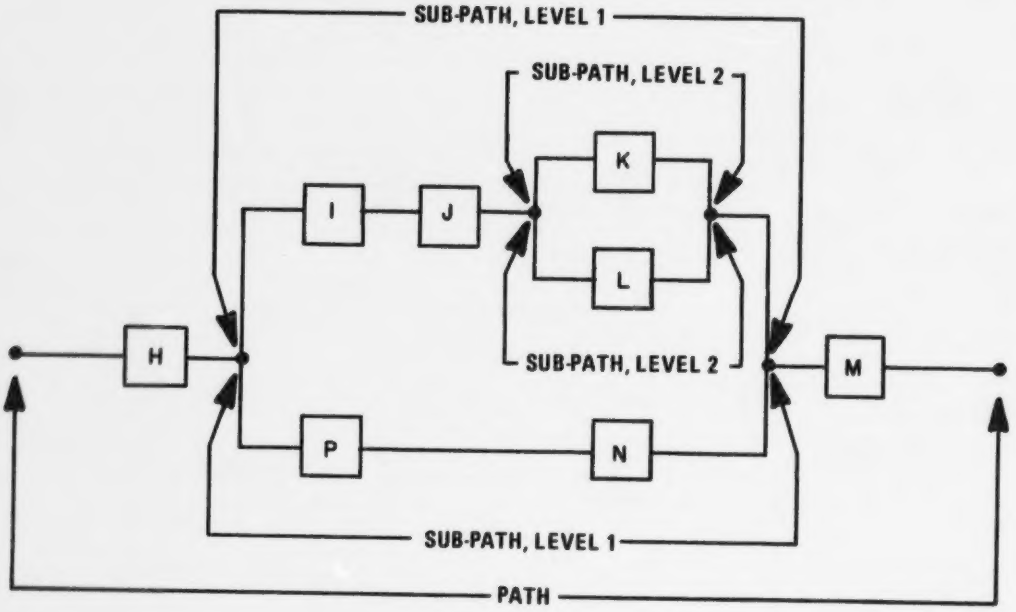


Figure 16. Illustration of Multi-level Sub-paths

One reason for performing such an analysis is to permit the evaluation of multiple utilization of single means to fulfill functions in several independent system elements. Examples of such multiple utilization may be found in both fully automatic and fully manual systems. In the former, one automatic station (a means) may perform the sample acquisition, analysis and recording function for a number of different water quality parameters (system elements). In the latter, a single piece of laboratory equipment may be used to perform all the analyses for a single parameter in all the segments of the basin.

The functional analysis is performed by first generating an information flow diagram such as those in Figure 15 for every system element and then creating a table of descriptive data such as that shown in Figure 17. The table is called the "Utilization Table." For each system element (segment—parameter pair), each path and sub-path is identified with a number. The single path associated with the entire system element must be numbered "1"; all other sub-paths are numbered arbitrarily. It is conceivable that path "1" may consist of a number of sub-paths and no serial means, as in Figure 18. Path "1" never has any paths parallel to it. For each path or sub-path in the system element, the following information is entered in the utilization table:

1. The normal status of the path or sub-path:

   1 — normally operating (always the status of the element path)

   $\left.\begin{array}{l}2\\ \cdot\\ \cdot\\ \cdot\\ N\end{array}\right\}$ the sequence of activation if normally stand-by (not valid for the element path)

SEGMENT NUMBER	PARAMETER NUMBER	PATH NUMBER	NORMAL PATH STATUS	PARALLEL SUB-PATHS	SERIES MEANS IN PATH	SUB-PATHS IN PATH

Figure 17. Format of Utilization Table

2. If a sub-path, the identification number of all parallel sub-paths (all sub-paths between the same two nodes)
3. The identification numbers of all means in series in the path or sub-path
4. The identification numbers of all the next lower-level sub-paths that form a part of the path or sub-path.

The means identification numbers may be assigned arbitrarily, one number to each identifiable unit in the entire surveillance system for which data on cost, accuracy, reliability, maintainability, survivability, etc., are available. It is not necessary to explicitly identify the level of each sub-path, since this information is implicit in the tabulated data. The computer programs described in Section VII automatically analyze these data for path level when needed.

Table 3 illustrates the results of the analysis for the system element shown in Figure 18. Thus, it is possible to develop a Utilization Table, such as Table 3, that relates the system means to their assignments in each system element. Such a table clearly shows the multiple utilization characteristic, as the means identification number will show up in the "Serial Means" column each time it is

Table 3. UTILIZATION TABLE

Seg No.	Param No.	Path No.	Normal Path Status	Parallel Sub-Paths	Series Means in Path	Sub-Paths in Path
i	j	1	1	—	—	3, 5
i	j	2	1	4	6, 7	—
i	j	3	1	5	1, 8	2, 4
i	j	4	1	2	4, 5	—
i	j	5	2	3	2, 3	—

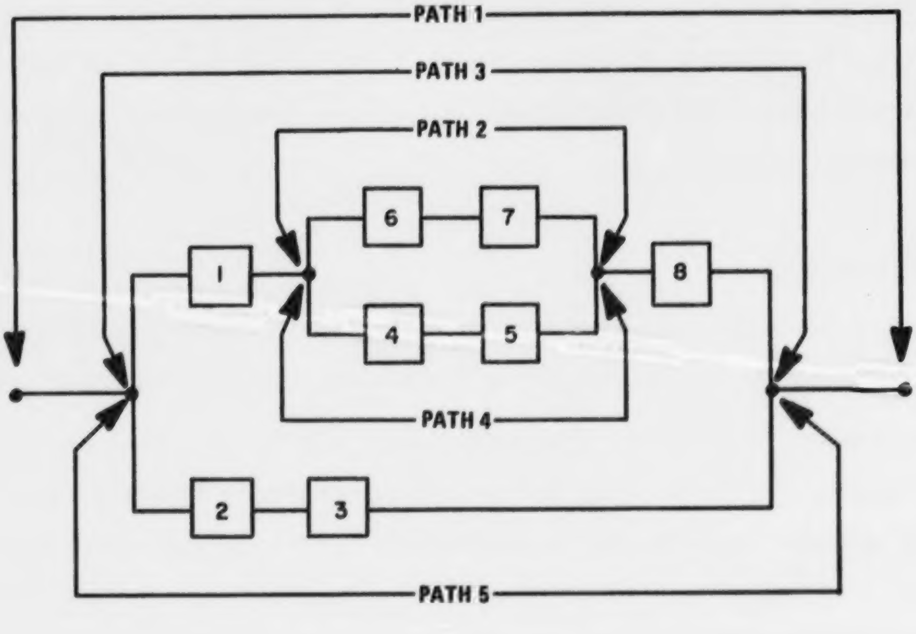

PATH 1
PATH 3
PATH 2
6
7
1
8
4
5
PATH 4
2
3
PATH 5

Figure 18. Illustration of Multi-Sub-path Element Path

assigned to a different system element. The table does not show the organizational structure within which the means operate, and it does not indicate the feasibility of actually achieving such a utilization pattern for the planned sampling scheme. Prior to preparing the Utilization Table, the system designer must have considered in detail such questions as the inherent capacity of the means and scheduling conflicts.

ANALYSIS OF SYSTEM COSTS

In order to compute the cost-effectiveness of the n^{th} candidate system (Γ_n), it is necessary to arrive at an estimate of the total system cost (K_{sys}). The development of those techniques of system cost estimation that are specific to the design of water quality surveillance systems are presented below. The objective of the development is a set of methods that assure that all applicable costs are included, while promoting convenient manipulation of costs as various candidates are examined.

Total System Cost

The total system cost of the candidate (K_{sys}) is defined in terms of the organizational framework described earlier in this section. Each system component, means or group, is assigned a cost in accordance with the basic concepts described below. For convenience, the cost assignment can be done once for all the system components that may be considered for inclusion in any candidate system. It is then possible to arrive at a total system cost for a particular candidate by summing the costs for only those means and groups incorporated in that candidate.

Thus, the total system cost is defined as:

$$K_{sys} = \sum K_m + \sum K_g \tag{9}$$

where K_m = the costs of the means included in the candidate system

K_g = the costs of the support groups necessary to the means included in the candidate system.

Both the organizational and functional analysis of the candidate must have been completed prior to computation of total system cost. The Utilization Table associated with the functional analysis is used to identify those means included in the candidate system. With that information the first term in equation (9) can be evaluated. The second term is evaluated using the organizational framework. The cost of a group is added to the total, if one or more lower-level groups or means associated with it are required by the candidate.

To clarify the cost summation, consider the following illustrations based on the organizational framework shown in Figure 13. If the Utilization Table for system candidate number one calls for incorporation of the boat and crew, but not the AA, GC, or BOD incubator, the total system cost for candidate 1 would include the following terms:

$$K_{sys}(1) = K_{boat} + K_{crew} + K_{field\ off.} + K_{field\ ops\ adm.} + K_{sys\ adm.} + \ldots \tag{10}$$

In contrast, a second candidate system that required two boats and crews from the same field office would have a total system cost including:

$$K_{sys}(2) = K_{boat\ 1} + K_{boat\ 2} + K_{crew\ 1} + K_{crew\ 2}$$

$$+ K_{field\ off.} + K_{field\ ops\ adm.} + K_{sys\ adm.} + \ldots \qquad (11)$$

Finally, a third candidate might require, in addition to a boat and crew, an AA. The resulting system cost would include:

$$K_{sys}(3) = K_{boat} + K_{crew} + K_{field\ off} + K_{field\ ops\ adm.}$$

$$+ K_{AA} + K_{lab} + K_{lab\ adm.} + K_{sys\ adm.} + \ldots \qquad (12)$$

Notice that the cost of the laboratory group is summed in the total system cost only when a laboratory means is required by the candidate under consideration. Notice also that the cost of the field office is included only once, no matter how many means associated with it are required by the system.

Cost of System Components

The costs used in estimating the total system cost are life-cycle costs, the total expected economic cost of the component over the expected lifetime of the system. For the purposes of water quality surveillance system design, the system lifetime is defined to be the system duration [3], the period over which the system is expected to maintain a fixed configuration.

In estimating the life-cycle costs of the means used to implement the water quality surveillance system, a number of factors must be considered. The actual estimating methods used by an individual system designer will be a function of personal preference and the fiscal structure of the organization that is to operate the system. The aim here is to highlight the major factors that must be incorporated in the estimates, no matter what detailed approach is employed.

It should be clear from the preceeding illustrations that the system designer must carefully separate those invariant costs associated with a group (no matter how many lower-level groups or means are active) from those costs that vary as a function of the sub-groups and means required. For example, candidate 2 above requires two boats and crews at the same field office. The costs associated with the field office are those costs that are due to the existence of the field office, no matter how many boats and crews use it. The costs associated with boats and crews are allocated directly to those means, so that a requirement for two boats and crews results in a doubling of those costs over a requirement for one of each.

Four basic costs must be considered in the estimation of cost for a means or group:

1. the cost to acquire the means or group
2. the cost to operate the means or group
3. the cost to maintain the means or group and
4. the residual value of the means or group at the end of the system duration.

Because of the parallelism in the estimation of cost for means or group, attention is confined to the means in the following. The discussion is perfectly applicable to groups as well.

In equation form, the cost of a means is:

$$K_m = K_{acq,m} + K_{op,m} + K_{maint,m} - K_{res,m} \tag{13}$$

Each of these terms requires discussion to fully define the economic costs included.

The cost to acquire the means (K_{acq}) includes both direct hardware costs and the cost of all engineering, planning, purchasing and installation actions associated with the initial establishment of an operational water quality monitoring system and specific to the means. (Under this definition, the overall costs of performing the total system design activities described in this report and in [3] are charged directly to the system level group, group 1.) Other economic costs include the cost to finance the acquisition cost, for example interest on bond issues, and the so called inheritance costs. The inheritance cost is the economic cost of employing an available resource on the system under design, thereby foregoing its use in any other activity. The inheritance cost is used to account for the idea that apparently free resources, such as surplus equipment, may, in fact, have a real cost which ought to be charged to the system.

The cost to operate the means (K_{op}) is the direct and indirect charges attributable to the performance of the system function. These charges include administrative and facilities overhead allocations (variable group costs), direct operational labor charges, and the cost of expendables and consummables, such as chemicals and electric power.

Similarly, the cost to maintain the means (K_{maint}) is the direct and indirect charges attributable to routine maintenance and non-routine repair of failures. In addition to direct labor, spares costs and allocated overhead expenses, there is also the cost associated with replacement of entire units. Such replacement is a matter of system administrative policy. Selection of means that are expected to require replacement within the system duration may result in an acceptable system effectiveness, if a mechanism is provided for their replacement. Fiscal mechanisms for planned replacement include direct purchase from capital budgets and sinking funds. These same mechanisms, plus insurance, may be used if system policy is to replace means that fail to survive due to catastrophic occurances, such as floods and ice jams. The costs of these fiscal mechanisms are maintenance costs and are included in K_{maint}.

Since many of the system means may survive the system duration, the means may be expected to have a residual value associated with them at that time. This residual value is of the same kind as the inheritance costs charged to the system acquisition cost for use of surplus means from previous systems. By subtracting the residual value from the cost of the means, only that portion of the useful life of the means actually employed in the system is charged to the system.

The reader is directed to [12], [15], and [16], if more extensive discussion of these costs is sought.

ANALYSIS OF SYSTEM EFFECTIVENESS

The other element of the cost-effectiveness ratio is the total system effectiveness (E_{sys}). The purpose of computing a system effectiveness is to provide a quantitative measure of the success of the system at achieving its objective. Thus, the computation of a system effectiveness depends on a definition of the system objective and a method of predicting the success of candidate systems relative to that objective. The following paragraphs present, first, the definition of total system effectiveness adopted for water quality surveillance systems. Then they examine in detail the factors that contribute to system effectiveness.

Once again, the objective of the development is a set of methods to assure that all applicable effectiveness factors are included, while promoting convenient manipulation of these factors as various candidates are examined.

Total System Effectiveness

For the design of water quality surveillance systems, the total system effectiveness (E_{sys}) is defined as the ratio of the expected number of (true) detections of violations to the expected number of violations. More precisely, E_{sys} is defined as:

$$E_{sys} = \frac{\text{Expected number of independent violations to be detected by the system over the system duration}}{\text{Expected number of independent violations in the basin over the system duration}} \qquad (14)$$

This definition of total system effectiveness is based on the assumed system objective, the concept of independent violations, and the concept of detection. It is similar to the definition of temporal sampling effectiveness (M, equation (3)) developed in [3]. The difference between equation (3) and the definition of total system effectiveness is in the spatial dimension. The temporal sampling effectiveness is concerned only with detection of violations that occur at a single monitoring site. The total system effectiveness deals with the detection of violations throughout a river basin by the entire monitoring system.

System Objective -

As in the previous study [3], it is assumed that the water quality surveillance system has the abatement objective. That is, the objective of the system is to detect every violation of the stream water quality standards. Thus, a reasonable measure of the success of the system is the percentage of violations actually detected, or, in the case of system design, the expected percentage detected.

Violation Concept -

An independent violation is said to come into existence whenever an upstream boundary to a region of the stream in the violation state is formed. The independent violation continues to persist as long as the associated upstream boundary persists. It ceases to exist whenever a definite upstream boundary ceases to exist.

The concept of independent violations is crucial to the definition of total system effectiveness. In a stream, violations typically extend over both space and time. It is conceivable that a given violation may be observed by the system at more than one point in space or more than once at any given point. Thus, care must be taken in the definition of an independent violation, so that multiple detections of the same violation may be discounted.

To permit such regions to be correctly identified and counted, a unique property of the region must be identified as characteristic of the region. The region can be described as a set of adjacent points on the stream where a water quality violation exists, that is, where a parameter concentration exceeds the established water quality threshold. The concept of a unique water quality threshold is selected in [3] on the basis of a detailed review of water quality standards. In general, severity of the violation is not considered in the standards. Thus, the violation is characterized as a concentration in excess of a simple threshold. Since all points within the region share this common description uniformly, the region can also be characterized by the location of its boundaries.

Of the two boundaries, the upstream boundary is selected arbitrarily as characteristic of the region. The downstream boundary would serve equally well.

The existence and location of the region boundaries is a function of time. Following its initial formation, such a region may subsequently divide into two or more separate regions when points within the region return to the non-violation state. Such a division is characterized by the formation of one or more new upstream boundaries. Similarly, two or more such regions may merge when intervening points change to the violation state. Such a merger is characterized by disappearance of the upstream boundaries of the downstream regions.

Figure 19 presents an example progression of independent violations in a simple river basin to illustrate the concept. Initially, there are no violations. Due to an increase in waste discharge at the upstream point source, violation "A" is formed and characterized by an upstream boundary to the region in violation of the standard. Similarly, violation "B" is initiated by the downstream source. As discharge at the upstream source continues to increase, the length of "A" increases until it eventually overlaps "B". Since an upstream boundary for "B" no longer exists, "B" ceases to exist as an independent violation. Later, the discharge from the upstream source decreases, causing "A" to contract. The violation due to the downstream source is now the sole cause of a violation at that point in the stream and a new violation ("C") is characterized by the reappearance of an upstream boundary at that source. Finally, the upstream discharge ceases and violation "A" ceases to exist, while "C" continues as the sole independent violation.

Thus, an independent violation is said to come into existence with the formation of an upstream boundary. The mode of formation can be either directly by transition from the non-violation state or by separation from a previously existing independent violation. Similarly, an independent violation is said to cease to exist when the upstream boundary disappears, either directly by transition to the non-violation state or by merger with another independent violation.

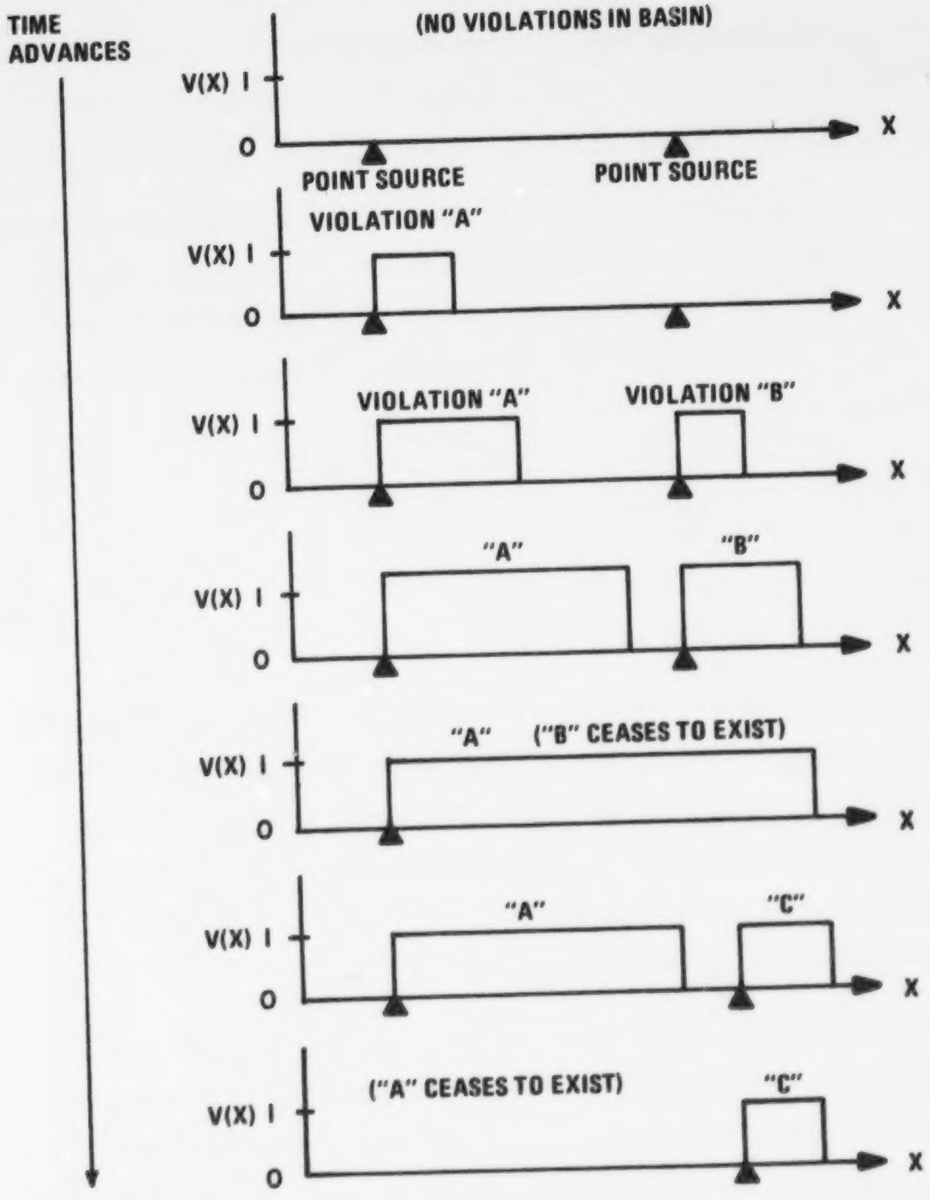

TIME ADVANCES
(NO VIOLATIONS IN BASIN)
V(X) 1
0
X
POINT SOURCE
POINT SOURCE
VIOLATION "A"
V(X) 1
0
X
VIOLATION "A"
VIOLATION "B"
V(X) 1
0
X
"A"
"B"
V(X) 1
0
X
"A"
("B" CEASES TO EXIST)
V(X) 1
0
X
"A"
"C"
V(X) 1
0
X
("A" CEASES TO EXIST)
"C"
V(X) 1
0
X

Figure 19. Example Progression of Independent Violations in a Basin

Detection Concept -

For purposes of the design method, an independent violation is said to have been detected when one or more observations taken within the region of the violation have values in excess of the threshold value set by the water quality standards.

The choice of the standards threshold as the criterion against which observations are compared is founded in statistical decision theory. The objective of statistical decision theory is to establish a basis for decision that tends to minimize the loss due to error in the presence of uncertainty. It considers four alternative conditions, in the present context:

$\Pr(D \mid V)$

$\Pr(\bar{D} \mid V)$ Type I error

$\Pr(\bar{D} \mid \bar{V})$

$\Pr(D \mid \bar{V})$ Type II error

where D implies detection, V implies violation and the bar over the symbol indicates "not". The second and fourth conditions are traditionally called "Errors of the First and Second Kind", respectively [17] (Figure 20). They are the probability of false dismissal and the probability of false detection. In general, system effectiveness should be penalized for errors and the formulation of system effectiveness should reflect consideration of both these errors.

For water quality surveillance systems, the source of the uncertainty is random error in the observed values of water quality. The goal is to select a decision criterion for detection in the presence of the random observational errors that tends to minimize both $\Pr(\bar{D} \mid V)$ and $\Pr(D \mid \bar{V})$. If the errors are assumed to have a symmetrical distribution (for example, gaussian), then it can readily be seen that the worst case for each type of error occurs when the true value of the water quality parameter is near the standards thresholds (Figure 21). In that

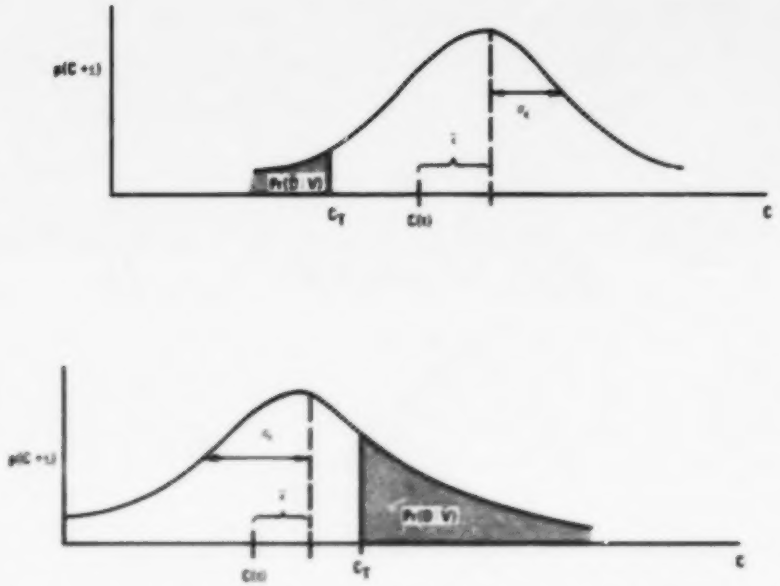


Figure 20. Illustration of Type I and Type II Errors for Gaussian Error Distribution with Mean ($\bar{\epsilon}$) and Standard Deviation (σ_ϵ)

water quality parameter is near the standards thresholds (Figure 21). In that case, it can be seen that both probabilities can be minimized only if the detection threshold (decision criterion) is set equal to the standards threshold (Figure 22). For all other cases, i.e., for the true value removed from the standards threshold, the probabilities of both types of error are lower than in this worst case condition.

Another reason for equating the decision point with the standards threshold is more pragmatic. It can be assumed that most agencies conducting surveillance will tend to use the standards threshold in the absence of detailed information on the observational errors. Moreover, it appears to be the most likely criterion used in legal enforcement actions.

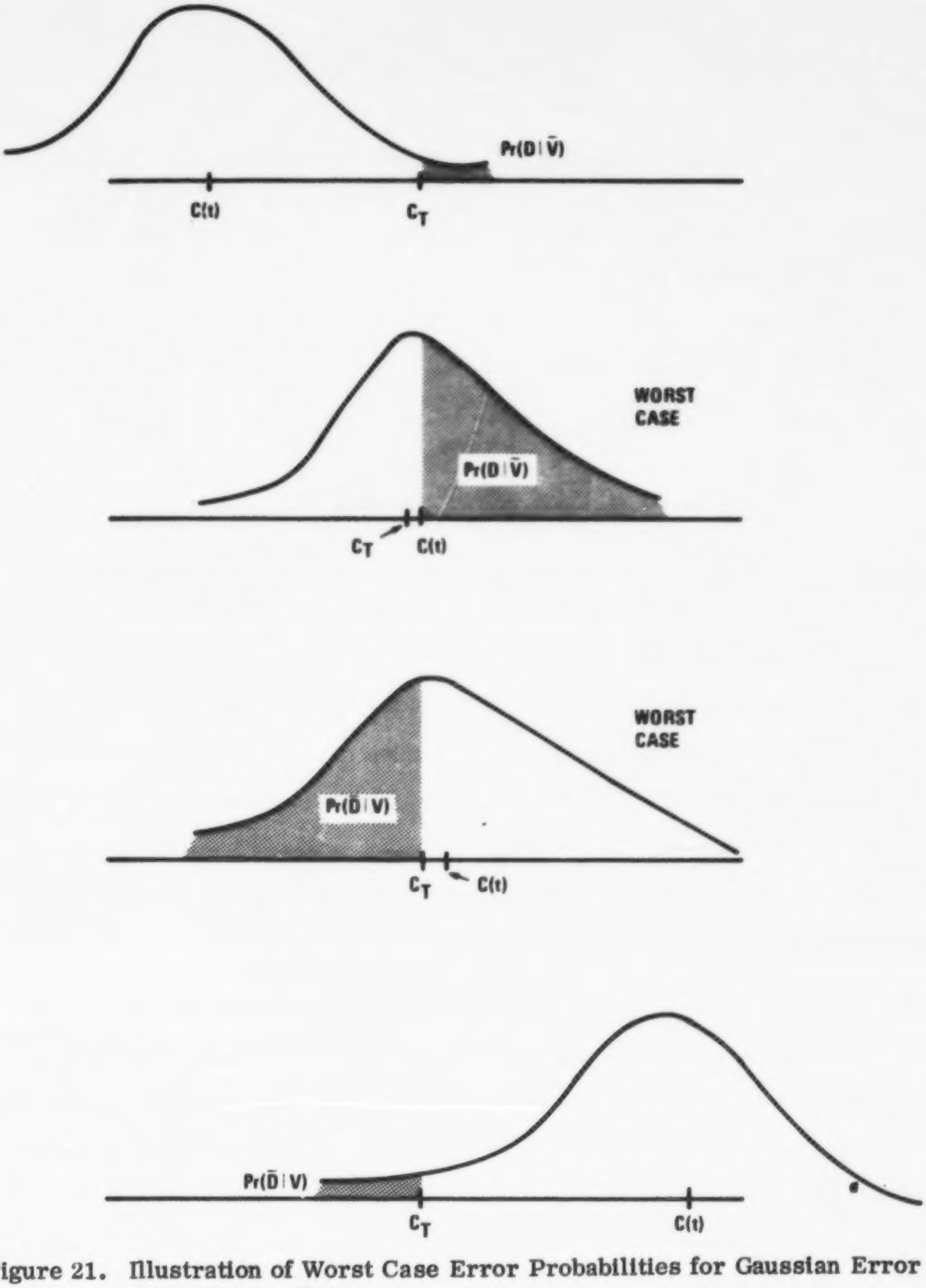

Pr(D | $\bar{V}$)
C(t)
C_T
WORST CASE
Pr(D | $\bar{V}$)
C_T
C(t)
WORST CASE
Pr($\bar{D}$ | V)
C_T
C(t)
Pr($\bar{D}$ | V)
C_T
C(t)

Figure 21. Illustration of Worst Case Error Probabilities for Gaussian Error Distribution ($\bar{\tau}$=0)

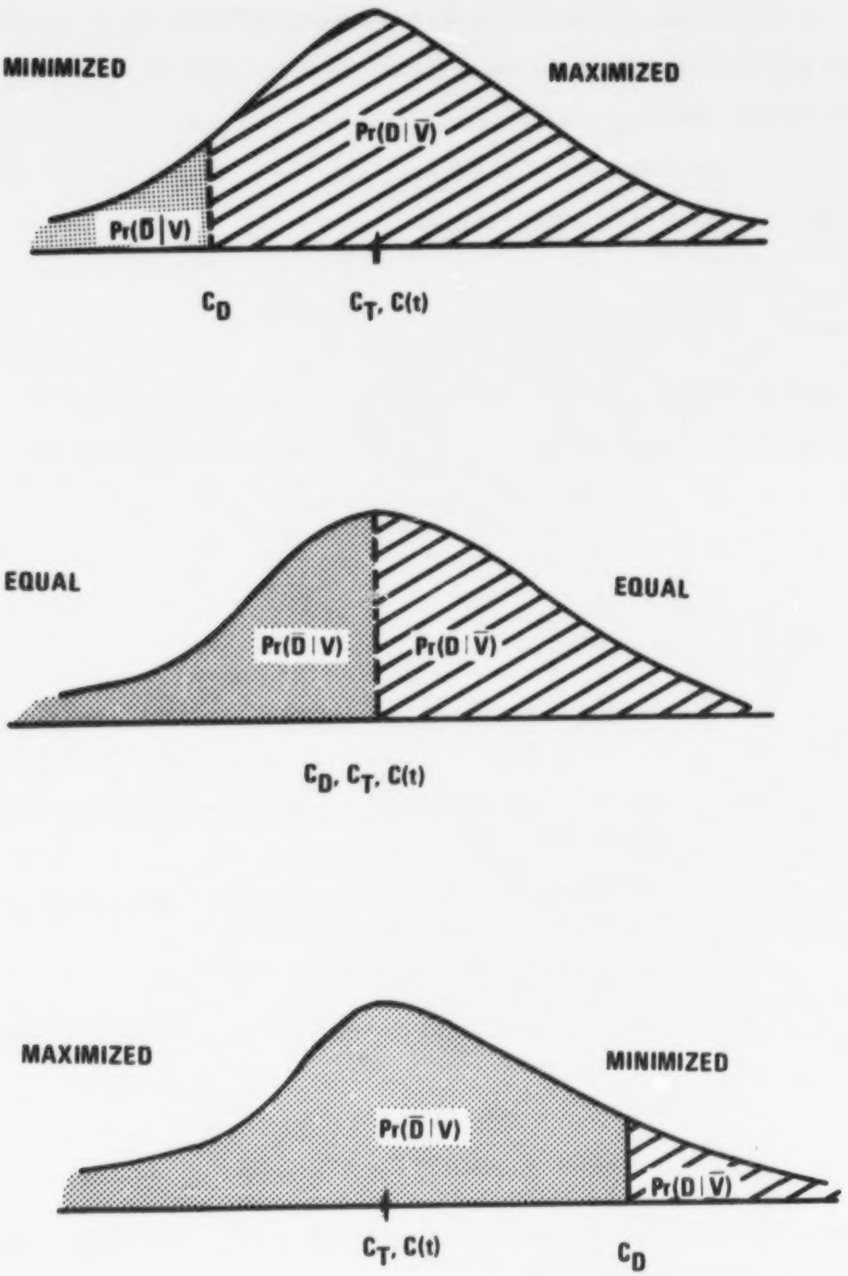

MINIMIZED
MAXIMIZED
Pr(D|V̄)
Pr(D̄|V)
C_D
C_T, C(t)
EQUAL
EQUAL
Pr(D̄|V)
Pr(D|V̄)
C_D, C_T, C(t)
MAXIMIZED
MINIMIZED
Pr(D̄|V)
Pr(D|V̄)
C_T, C(t)
C_D

Figure 22. Illustration of Effect of Decision Threshold, C_D, on Error Probabilities for Worst Case Condition ($C(t) \approx C_T$)

Thus, an independent violation is said to be detected when one or more observations of that violation have values in excess of the standards threshold. In counting detections, multiple observations of the violation state are ignored; the violation is considered to have been detected once, no matter how many observations indicating the violation state are taken.

Approximate Mathematical Formulation

In the development of the cost-effectiveness methods, an approximate mathematical form of the total system effectiveness is used. The approximate form is written as:

$$E_{sys} = \frac{\sum_{k=1}^{K} \sum_{j=1}^{J} n_d^* (i_k, j)}{\sum_{i=1}^{I} \sum_{j=1}^{J} n_v^{**} (i, j)} \qquad (15)$$

where $n_v^{**}(i, j)$ = the expected number of independent violations that occur for parameter j in segment i

$n_d^*(i_k, j)$ = the expected number of independent violations of parameter j detected in monitored segment i_k

I = the total number of segments in the basin

J = the total number of parameters included in the system design

K = the total number of monitored segments

i_k = the index number of the k^{th} monitored segment.

The approximate formulation is based on the assumption that the surveillance system is a relatively sparse network of monitoring stations. Under the assumed sparse conditions, violations that commence upstream of or in a monitored segment have a low likelihood of continuing downstream to the next monitored segment. This effectively eliminates the need to consider events in which an upstream station fails to sense a violation when a downstream station does. The same result would be achieved if the effectiveness of each individual system element, $E(i_k, j)$, were high, that is, if $n_d{}^* (i_k, j)$ were nearly equal to the number of violations occuring in the monitored segment.

The superscript asterisks are used to define the two different types of violations ennumerated by $n_d{}^*$ and $n_v{}^{**}$. Three types of violations can be defined with respect to a segment i. They are:

1. Type 1 Violation—a violation in segment i, that begins anywhere downstream of segment ℓ and ends anywhere (downstream of i).
2. Type 2 Violation—a violation in segment i, that begins in segment i and ends anywhere.
3. Type 3 Violation—a violation in segment i, that begins anywhere and ends anywhere.

The second type of violation is the kind associated with the superscript **, while the first type is associated with the superscript *, if $i = i_k$ and $\ell = i_{k-1}$ (k - 1 indicating the next upstream monitored segment) (Figure 23). The third type of violation is not used in the present methods. It was used in [3] for computation of initial segment priority and is presented here for comparison with types 1 and 2.

Since only those violations that have an upstream boundary in segment i contribute to $n_v{}^{**} (i, j)$, the summation in the denominator of equation (15) is clearly the total expected number of violations in the basin.

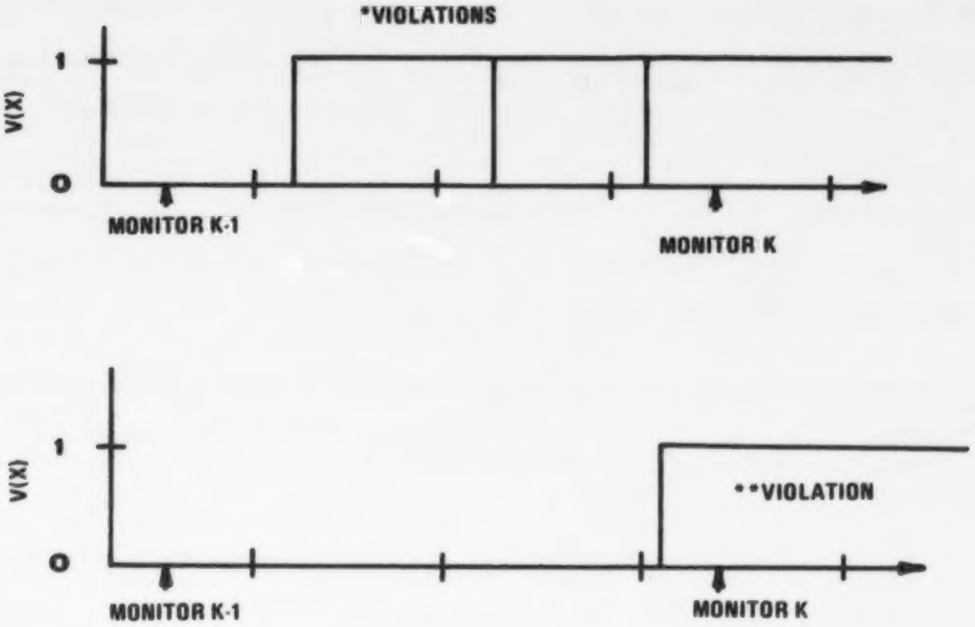


Figure 23. Illustration of Violation Types

The numerator of equation (15) is a conservative estimate of the expected number of detections, since it ignores the (presummably) small expected number of violations that are not detected in segment i_{k-1} and are detected in segment i_k. Included in n_d* are those violations that begin anywhere in the interval between and including segments i_{k-1} and i_k, and that extend to segment i_k. Those violations that both begin and end in the interval are not counted since there is no chance that they would be detected by the system.

A complete discussion of the development of equation (15) may be found in Appendix B. It should be clear from this expression that the measure of system performance used here constitutes a shift in emphasis from the concept of segment priority developed in [3]. (See Section VII for a discussion of this point.)

Effectiveness of System Elements

The effectiveness of the individual system element is represented in the numerator of equation (15) by $n_d^* (i_k, j)$. In a given segment for a given parameter, the expected number of detections can be related to the expected number of violations by:

$$n_d^* = \Pr (D \mid V)\, n_v^* \tag{16}$$

where n_v^* is the expected number of type 1 violations.

The factors contributing to the effectiveness of a system element may be determined by considering those events that must take place to achieve the detection.

Given a violation in a segment in which a station is located, the following must be jointly true:

1. one or more samples must be scheduled during the period of the violation
2. the method of observation and analysis must be sensitive enough to detect the violation
3. the system element must not have failed either:
    a) in a repairable mode, or
    b) in an irrecoverable mode.

The first two of these events relate to whether or not the system element is capable (c) of detecting the violation when operating normally. They are dependent on the complex interaction between the known characteristics of the system element and the expected characteristics of the violation process. The third event is entirely independent of the violation process, being solely dependent on the characteristics of the system element and events external to the system, such as vandalism and weather. The two types of failure included in the third item may be treated separately, because they have different properties. The system element has survived (s) if it has sustained no failure that cannot be repaired. Given that it survives, the system must also be available (a); it must not have failed and be under repair.

The effectiveness of the system element may be written as:

$$n_d^* = \Pr(D \mid V)\, n_v^* = \Pr(\underline{c},\ \underline{a},\ \underline{s} \mid V)\, n_v^* \qquad (17)$$

That is, the effectiveness of a system element is equal to the joint probability that the element is capable of detecting the violation and available to detect it and has survived long enough to detect it, given that a violation occurs. Because availability and survivability (these two terms are defined more precisely below) are both independent of the violation process, equation (17) may be written as:

$$n_d^* = \Pr(D \mid V)\, n_v^* = \Pr(\underline{c} \mid V,\ \underline{a},\ \underline{s})\, \Pr(\underline{a} \mid \underline{s})\, \Pr(\underline{s})\, n_v^* \qquad (18)$$

Each of the probability terms in equation (18) has been given a name for clarity in discussion. They are:

$$\begin{aligned} &(\Pr\,(\underline{c} \mid V,\ \underline{a},\ \underline{s})\ n_v^*) = \text{Capability} = C \\ &\Pr\,(\underline{a} \mid \underline{s}) = \text{Availability} = A \\ &\Pr\,(\underline{s}) = \text{Survivability} = S \end{aligned} \qquad (19)$$

Thus, the effectiveness of the system element is:

$$n_d^* = C \cdot A \cdot S \qquad (20)$$

As will be seen below, capability has been carefully defined to include n_v^*. This permits use of mathematics developed for [3] in the present context.

ESTIMATION OF SYSTEM EFFECTIVENESS

The estimation of system effectiveness requires the estimation of two quantities: $n_d^*(i_k, j)$ and $n_v^{**}(i, j)$. The approach used in computing each of these quantities is described in the following.

Estimation of Number of Violations

Computation of the denominator for equation (15) requires estimates of the $n_v^{**}(i, j)$. By extension from [3]:

$$n_v^{**}(i, j) = \frac{1}{T_0^{**}(i, j) + T_1^{**}(i, j)} \tag{21}$$

where T_1^{**} is the expected duration of a type 2 violation and T_0^{**} is the expected interval between type 2 violations. Estimation of the necessary values for T_0^{**} and T_1^{**} is discussed later in this section.

Estimation of Element Effectiveness

Estimation of the effectiveness of each system element, $n_d^*(i_k, j)$, requires the estimation of each of the components of effectiveness: capability, availability and survivability. These, in turn, depend on the properties of the means assigned to the system element and on the organization of those means.

For purposes of this study, it has been assumed that the necessary information on individual means will be available to the system designer. It is not the intent of this report to provide instruction in the performance of the test programs necessary to obtain these data for hardware equipments. Neither is it intended to develop methods for estimating these properties for human components of the system. The reader is referred to the literature, e.g., [12], [13], and [14], for these techniques. It is wholly within the prerogatives of the governmental agencies operating water quality surveillance systems to expect and require these data from the hardware manufacturers.

Given the appropriate data on the system means, the estimation method must combine these data to reflect the influence of system configuration on system effectiveness. The approach used differs for each of the three components of element effectiveness. These will be discussed individually below, survivability first, followed by availability and capability.

Estimation of Survivability -

Survivability is, literally, the probability that the system element has experienced no unacceptable, irrecoverable failure since it was "turned on".

By "irrecoverable failure" is meant a failure for which no provision has or can be made to repair or replace the failed means. As discussed under Analysis of System Costs, the incorporation of such a provision to back up catastrophic failures is a matter of system administrative policy that must be decided during the system design. If the back-up is, for example, a replacement unit kept at a protected site, the unit is incorporated in the system flow diagram as a stand-by path. If the back-up requires activation of a materially different surveillance system, then it is not included in the flow diagram. It is analyzed as if it were a separate candidate system and handled according to equation (8).

An "unacceptable failure" is any failure or combination of failures of the means associated with the system element that results in an interruption of the flow of information in the element path. Such an interruption occurs whenever a means fails and no back-up exists to take its place, either because there is no back-up or because the back-up has also failed.

For example, consider the simple system element diagrammed in Figure 24. The normal condition of the system element is State 0. States 1 and 6 constitute unacceptable failure states for the element, since all possible information flow routes are blocked in each case. While failures have occurred in States 2 and 4, they are acceptable, since the element continues to function normally. It should be noted that the possibility for off-line failure of the stand-by means is included.

If the unacceptable failures illustrated in Figure 24 are irrecoverable failures, then the system element has failed to survive. That is, since there is no way to return a failed means to service, there is no way to return the system element to an acceptable state and the system element will be out of service from the time of failure forward.

Thus, the estimation of survivability requires the estimation of the probability that the system element remains in an acceptable state for the system duration. The survivability of the system element is a function of the survivability of the associated means and the configuration of those means in the element.

For purposes of this development, it is assumed that the survivability of a means may be described by a Poisson process. That is, the following assumptions about the failure process are made:

1. the probability of a failure in the interval $(t, t + dt)$ is λdt
2. the probability of more than one failure in the interval $(t, t + dt)$ is of order $O(dt) \approx 0$.

The failure rate, λ , of the means is assumed to be a constant with respect to time. It may, however, take on different values depending on whether or not the means is in operating or stand-by status.

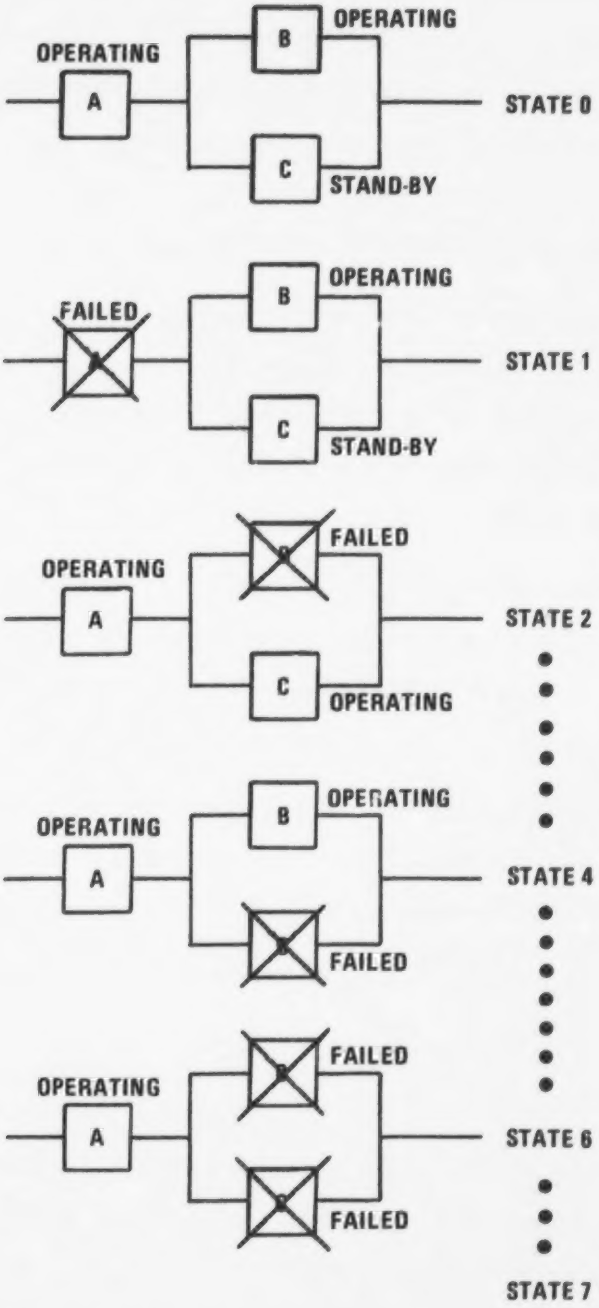

OPERATING
B
OPERATING
A
STATE 0
C
STAND-BY
B
OPERATING
FAILED
STATE 1
C
STAND-BY
FAILED
OPERATING
A
STATE 2
C
OPERATING
B
OPERATING
OPERATING
A
STATE 4
FAILED
FAILED
OPERATING
A
STATE 6
FAILED
STATE 7

Figure 24. Failure States for Typical Three-Means Element

The assumption of a Poisson process is made primarily for purposes of tractability. It is an assumption that is almost traditional in reliability and maintainability theory (see for example [13] and [14]). In making it, all temporal variability in the failure process is ignored. In the present case, such variations as the higher likelihood of ice floes in early spring and of floods in late spring are not considered for their impact on survivability. While these variations may, in fact, be important in detail, the objective of the project is to provide a system design method based on reasonable engineering assumptions. It is believed that the results of any comparison between alternative surveillance systems will be comparatively insensitive to this engineering assumption.

The number of different failure states that a system element may assume is:

$$N_s(i_k, j) = 2^{M(i_k, j)} \tag{22}$$

where M is the number of means associated with the element. This is simply the number of different combinations of the M means associated with the element.

Transitions from one failure state to another may occur through the failure of an additional means. For example, in Figure 24 the transition from State 2 to State 6 corresponds to failure of means "C". The probability of such a transition in the interval (t, t + dt) is:

$$\lambda_{Co}\, dt$$

where λ_{Co} is the failure rate of means C, while it is operating (i.e., not in standby).

Information on the N_s^2 possible transitions can readily be organized into an N_s by N_s square matrix, called the transition matrix. Figure 25 illustrates the matrix for the three-means system element shown in Figure 24. There are

$$\begin{array}{c|cccccccc}
 & \multicolumn{8}{c}{\text{TO-STATE}} \\
 & 0 & 1 & 2 & 3 & 4 & 5 & 6 & 7 \\
\hline
0 & 1-(\lambda_A+\lambda_B+\lambda_C) & \lambda_A & \lambda_B & 0 & \lambda_C & 0 & 0 & 0 \\
1 & & 1-(\lambda_B+\lambda_C) & 0 & \lambda_B & 0 & \lambda_C & 0 & 0 \\
2 & & & 1-(\lambda_A+\lambda_C) & \lambda_A & 0 & 0 & \lambda_C & 0 \\
\text{FROM-STATE}\ 3 & & & & 1-\lambda_C & 0 & 0 & 0 & C \\
4 & & & & & 1-(\lambda_A+\lambda_B) & \lambda_A & \lambda_B & 0 \\
5 & & \text{\huge 0} & & & & 1-\lambda_B & 0 & \lambda_B \\
6 & & & & & & & 1-\lambda_A & \lambda_A \\
7 & & & & & & & & 1
\end{array}$$

Figure 25. Sample Survivability Transition Matrix

$2^3 = 8$ possible failure states. The matrix is organized so that the rows represent the state at time t (from-state) and the columns represent the state at time t + dt (to-state). Since there is no possibility for repair of a failed means, all λ's below the diagonal are zero. The upper triangle is composed of the λ's for each possible transition due to failure of a single means. Transitions corresponding to failure of two or more means are assumed to have probability zero. The dt's are not written in the matrix, but are assumed present. The diagonal elements correspond to the probability of remaining in the initial state for the interval (t, t + dt); they are equal to 1 - (sum of the transition probabilities).

It is shown in [13] that the probability, $P_n(t)$, of the system element being in State n at time t can be derived directly from the transition matrix. The state probability vector, $\overline{P}(t)$, is defined as:

$$P(t) = [P_0(t),\ P_1(t),\ .\ .\ .\ .\ ,\ P_{N_s}(t)] \qquad (23)$$

The vector of Laplace transforms of the state probabilities, $\bar{P}(s)$, is defined as:

$$\bar{P}(s) = [P_0(s),\ P_1(s),\ .\ .\ .\ .\ ,\ P_{N_s}(s)] \qquad (24)$$

then, from [13]:

$$\bar{P}(s) = \bar{P}(0)\ (s\bar{\bar{I}} - \bar{\bar{B}})^{-1} \qquad (25)$$

where $\bar{\bar{I}}$ = the identity matrix
$\bar{\bar{B}} = \bar{\bar{S}} - \bar{\bar{I}}$
$\bar{\bar{S}}$ = the survivability transition matrix

and the negative exponent implies matrix inversion. Finally, the desired probability is obtained from the inverse Laplace transform:

$$P_n(t) = \mathcal{L}^{-1}\ (P_n(s)) \qquad (26)$$

Using equation (26), the survivability is computed as:

$$S = \sum_k P_{n_k}(T) \qquad (27)$$

where the n_k refers to the k^{th} acceptable failure state and T is the system duration.

Thus, estimation of survivability consists of the following steps:

1. preparation of the transition matrix, $\bar{\bar{S}}$
2. determination of the acceptable failure states

3. computation of the $P_{n_k}(t)$ from the transition matrix

4. computation of S from the $P_{n_k}(T)$.

Estimation of Availability -

Availability is the probability that the system element is not in an unacceptable state of temporary failure at any time, t, after initial "turn on", given that it has survived.

A "state of temporary failure" means a condition of failure for which repair is possible, but has not been completed. The emphasis here is on repair of a failure, not on routine maintenance downtime. Thus, the process is a random one, rather than periodic.

As in survivability, an unacceptable failure is any failure or combination of failures of the means associated with the system element that results in an interruption of the flow of information in the element path.

In analyzing the system element for availability, the method of describing the element is essentially the same as that used for survivability. An information flow diagram such as those shown in Figure 24, may be prepared for the system element. The availability flow diagram for a given element may be expected to differ from the survivability flow diagram in many cases. One major point of difference is the exclusion of some back-up paths from the availability diagram. The excluded back-up paths are those that would not be activated for short term system failures. For example, total loss of an entire automated station (failure to survive) might be cause to mobilize a complete replacement unit. Temporary, repairable failure of an associated telemetry unit might activate a stand-by recorder, but would not be likely to require complete replacement of the unit.

Another major point of difference is the identification of the means associated with the system element. While survivability is concerned with total loss of facilities physically near enough to be destroyed as a group, availability is frequently concerned with the sub-units of such grouping.

In estimating availability, it is assumed that both the failure process and the repair process are Poisson processes. As in survivability, the assumption is made primarily for tractability. The approximations involved in making the assumption are discussed in [13]. The Poisson process ignores such considerations as the wearing out of mechanical parts, that would increase the failure rate over time. It also assumes that the equipment is designed so that high likelihood failures are more easily repaired than low likelihood failures. For the purposes of system-level design of water quality surveillance systems, it is felt that ignoring such factors is a reasonable engineering approximation.

A transition matrix can be prepared for availability in the same was as the matrix for survivability, except that transitions from failed to non-failed states must be considered. The number of possible system states is, as before, $N_s = 2^M$. The lower triangle is composed of transitions from failed to repaired status; the upper triangle is, as before, composed of failure transitions. Again the diagonal elements of the matrix are the probabilities of remaining in the state for the interval (t, t + dt).

Figure 26 illustrates the availability transition matrix for the system element shown in Figure 24. The failure rate of each means is shown as a λ and the repair rate as a μ.

It is shown in [13] that a system having the properties described above tends toward an equilibrium availability state as time increases. That is, the availability at any time, t, is independent of the time. Such a condition results in a

$$
\begin{array}{c|cccccccc}
\text{STATE} & 0 & 1 & 2 & 3 & 4 & 5 & 6 & 7 \\
\hline
0 & 1-(\ ) & \lambda_A & \lambda_B & 0 & \lambda_C & 0 & 0 & 0 \\
1 & \mu_A & 1-(\ ) & 0 & \lambda_B & 0 & \lambda_C & 0 & 0 \\
2 & \mu_B & 0 & 1-(\ ) & \lambda_A & 0 & 0 & \lambda_C & 0 \\
3 & 0 & \mu_B & \mu_A & 1-(\ ) & 0 & 0 & 0 & \lambda_C \\
4 & \mu_C & 0 & 0 & 0 & 1-(\ ) & \lambda_A & \lambda_B & 0 \\
5 & 0 & \mu_C & 0 & 0 & \mu_A & 1-(\ ) & 0 & \lambda_B \\
6 & 0 & 0 & \mu_C & 0 & \mu_B & 0 & 1-(\ ) & \lambda_A \\
7 & 0 & 0 & 0 & \mu_C & 0 & \mu_B & \mu_A & 1-(\ )
\end{array}
$$

Figure 26. Sample Availability Transition Matrix (where the ( ) indicate the sum of all the row transition probabilities)

set of linear algebraic equations based on the availability transition matrix, of the form:

$$0 = \sum_{i=1}^{N_s} A_{ij} P_i, \qquad j = 1, N_s \tag{28}$$

plus the identity:

$$1 = \sum_{i=1}^{N_s} P_i \tag{29}$$

where the A_{ij} are the elements of the availability transition matrix, $\bar{\bar{A}}$, and P_i is the probability of being in state i.

The system of linear equations can be solved directly for the P_i's. Then the availability, A, can be computed as:

$$A = \sum_k P_{n_k} \tag{30}$$

where n_k refers to the k^{th} acceptable failure state.

Thus, estimation of availability consists of the following steps:

1. preparation of the availability information flow diagram
2. preparation of the transition matrix, $\bar{\bar{A}}$
3. determination of the acceptable failure states
4. solution of equations (28) and (29) for the P_i
5. computation of A from the P_{n_k}.

Estimation of Capability -

The concept of element capability is an extension of the concept of sampling effectiveness developed in [3] (see Section IV). In that development, consideration is given to the effect of discrete sampling of the river on the probability of detection of a violation, given that a violation occurred. It is assumed in [3] that the violation is detected if a sample is taken during the violation. It is also assumed that the sampling process continues without breaks for the duration of the system and that all samples are taken at the preferred station location in each segment.

The above restrictions are removed in estimating element capability. In addition to the effect of periodic sampling, capability incorporates the following factors:

1. the effect of routine maintenance downtime
2. the effect of designing the system so that samples are taken at a point other than the preferred station location
3. the effect of random errors in the analytical process.

Other factors may be expected to affect the capability of the system element, but they have been assumed to be negligible. Such factors as the random error in locating the station and the random error in timing the sample are considered small, in comparison to the factors included in capability.

Capability (C) is defined above as (equation (19)):

$$C = \Pr[\underline{c} \mid V, \underline{a}, \underline{s}]\, n_v^* \tag{31}$$

Implicit in the definition is knowledge of the preferred station location, x_m, the designed station location, x, the effective sampling interval, Δ_e, the mean error of the analytical process (the calibration accuracy), $\bar{\epsilon}$, and the standard deviation of the analytical process (the precision), σ_ϵ. Thus, if the explicit condition that the element be available and survived is dropped, capability may be written as:

$$C = \Pr[\underline{c} \mid V, x_m, x, \Delta_e, \bar{\epsilon}, \sigma_\epsilon]\, n_v^* \tag{32}$$

The above form is equivalent to the expected number of violations that would be detected if the system never failed. That value could be computed directly by extension of the equation for expected number of detections developed in [3]. Appendix C presents a thorough development of that approach.

Unfortunately, the direct extension of the earlier work involves variables that are extremely difficult to estimate from the available data using a computer. Appendix C discusses these problems.

In its place, a less elegant, more pragmatic approach has been used. That approach also draws on the results of the previous study, in combination with a straightforward consideration of sampling error. The result is clearly an approximation and is shown to be conservative, i.e., to underestimate capability.

The expected number of independent violations that will be sampled at least once at a given observation point can be computed directly from the equation for expected number developed in [3]. The only adjustments necessary are in the location considered, the actual sampling location instead of the preferred sampling location, and in the sampling interval used. Thus, the expected number of violations sampled (n_s^*) is:

$$n_s^* = \frac{T_0^* T_1^*}{\Delta_e \left[(T_0^*)^2 - (T_1^*)^2\right]} \left[\exp\left(\frac{-\Delta_e}{T_0^*}\right) - \exp\left(\frac{-\Delta_e}{T_1^*}\right)\right] \tag{33}$$

where the T_0^* and T_1^* are estimated for type 1 violations at the actual sampling location and the Δ_e is the sampling interval adjusted for routine maintenance. The approach used in estimating T_0^* and T_1^* is discussed later in this section.

The effect of routine maintenance is to modulate the sampling process, periodically turning it off. The result is an average, or effective, sampling period, Δ_e, that is slightly greater than the sampling interval of the sampling process, Δ. The difference between Δ_e and Δ depends on the maintenance policy, as developed in Appendix D. If the next sample following return to service is taken in phase with the previous schedule:

$$\Delta_e = \frac{N_d + N_u + 1}{N_u + 1} \Delta \tag{34}$$

where $N_d = \text{Integer}\ (T_d/\Delta)$

$N_u = \text{Integer}\ (T_u/\Delta)$

T_d & T_u = the scheduled downtime and maintenance interval (uptime), respectively.

If the next sample is taken immediately following return to service and the sampling schedule adjusted to the new phase, then:

$$\Delta_e = \frac{N_d \Delta + T_u}{N_u + 1} \tag{35}$$

The probability of a given violation that is sampled at least once being detected is a function of the sampling error and the number of times that the violation is sampled.

A conservative estimate of number of independent observations of the average independent violation (n_o) is:

$$n_o = \frac{T_1^*}{\Delta_e} \tag{36}$$

where T_1^* is the average duration of a type 1 violation at the station location. This estimate is conservative, since T_1^* is less than the average duration of violations that are sampled at least once. That is, the shortest violations tend not to get sampled at all and are not counted in n_s^*. Thus, they should also be left out of the n_o computation. They are not, so the estimate is conservative.

The probability of falsely dismissing a violation, on the basis of a single observation, $\Pr[\bar{D} \mid V]$, is a function of the mean error, $\bar{\epsilon}$, the standard deviation of the error, σ_ϵ, the detection threshold (equal to the standards threshold), C_T, and the true state of nature at the time of observation, C. Since C is never known, a conservative estimate of Pr $[\bar{D} \mid V]$ is the maximum probability of error, P_m, that is obtained when $C = C_T$. If the observational errors are assumed gaussian:

$$P_m = \int_{-\infty}^{C_T} N(C_T + \bar{\epsilon},\ \sigma_\epsilon) = \int_{-\infty}^{-\epsilon/\sigma_\epsilon} N(0,\ 1) \tag{37}$$

Thus, a conservative estimate of the probability of falsely dismissing the average violation that is sampled is:

$$\Pr [\bar{D} \mid V] = (P_m)^{n_o} \tag{38}$$

and the probability of making the correct decision is

$$\Pr [D \mid V] = 1 - \Pr [\bar{D} \mid V] = 1 - (P_m)^{n_o} \tag{39}$$

Combining the two factors, the capability of the system element is conservatively estimated as:

$$C = \left[1 - (P_m)^{n_o} \right] n_s^* \tag{40}$$

Estimation of T_0 and T_1

The foregoing methods for evaluating system effectiveness depend on the availability of estimates for T_0^*, T_1^*, T_0^{**} and T_1^{**} in equations (21) and (33).

The estimation approach used in the analysis of cost-effectiveness is essentially identical with that developed in [3] for estimation of T_0 and T_1, the expected values characteristic of a type 3 violation. The threshold concentration in the stream quality standards is replaced by the threshold flow that results in stream quality reaching the standards threshold. The USGS stream gaging station records are then searched for periods in which stream flow fell below the threshold value in the reach under consideration. The associated durations are recorded and the expected durations estimated by the average values of the violations found in the historical records. That is:

$$T_0 \approx \frac{1}{N} \sum_{n=1}^{N} t_{on}$$
$$T_1 \approx \frac{1}{N} \sum_{n=1}^{N} t_{1n} \tag{41}$$

where the t_{on} and t_{1n} are the interval preceeding and the duration of the n^{th} violation, respectively.

Estimation of $T_0{}^*$, $T_1{}^*$, $T_0{}^{**}$, and $T_1{}^{**}$ requires the counting of only those violations that fit the appropriate type descriptions. In searching the historical flow data, comparisons must be made to determine the spatial extent of each violation found in the i^{th} segment. For the n^{th} violation, $t_{on}{}^*$ and $t_{on}{}^{**}$ are considered to be the interval preceeding the n^{th} violation of the corresponding type, even though a violation of a different type may exist in the i^{th} segment during that period.

SECTION VII

DESIGN OF WATER QUALITY SURVEILLANCE SYSTEMS

With the development of the cost-effectiveness design methods presented in Section VI, a complete quantitative design method encompassing all the factors in Figure 1 can be assembled and computer programs can be prepared. The quantitative design method is a result of merging the preliminary design methods of [3] with the methods for analysis of system cost-effectiveness described in this report. This section provides a summary of the design methods and the computer programs used to implement those methods. Following the summary are instructions on the preparation of input data and use of the programs. Details of the computer program development may be found in Appendix E.

OVERVIEW OF DESIGN METHODS

The overall process of designing a river basin surveillance system is diagrammed in Figure 12. That process can be thought of as composed of two design phases, described in the following paragraphs.

The first, or preliminary design, phase is directed at developing a sufficient description of the river system to allow the designer to rationally allocate his surveillance resources. The description consists of: 1) a set of preferred locations for the observation of the water quality parameters under consideration, 2) a measure of the importance of making observations at each of those preferred locations, and 3) data that permit a preliminary evaluation of the efficiency of various sampling rates at detecting water quality violations. Using this description of the river basin as it relates to surveillance, the system designer may then select one or more candidate surveillance systems for further evaluation.

During the second, or final, design phase, the system designer selects a preferred surveillance system configuration on the basis of his evaluation of the candidates. The evaluation considers three aspects of the system design: 1) the expected interaction between the surveillance system (working according to its design specifications) and the natural system, 2) the likelihood that the system is not meeting its specifications, and 3) the anticipated cost of the system candidate. Using the information obtained from his evaluation, the system designer may either select one of the candidates for implementation or evaluate additional candidates designed on the basis of the knowledge gained during the first evaluations.

The computer programs discussed in this section are designed to support the system designer in both the preliminary and the final design phases of the system design process. They are intended to provide for use of the computer in the most tedious and complex aspects of the design selection and evaluation process. No attempt is made to automate all the activities required by system design. For example, it is still up to the designer to assure himself that the sampling schedule specified for a candidate is achievable with the organization and resources allocated to the candidate.

Based on the experience of [3] and the early engineering of the current project, several areas can be identified as being appropriate for computerization. These areas are: 1) the description (model) of the river basin, 2) the estimation of the expected durations T_0 and T_1 from USGS flow records, and 3) the computation of availability and survivability. The labor involved in manually computing the results of a river basin mathematical model is documented in [3]. Inclusion of a computerized basin model needs no further justification. The computation of $T_0{}^*$, $T_1{}^*$, $T_0{}^{**}$, and $T_1{}^{**}$ requires the search of long USGS flow records (many years) for threshold crossings. Detailed consideration must be given to the spatial persistence of the violation. In a typical basin described by 40 reaches, design of a system to detect violations of 5 water quality parameters, using a 5 - year (1825 days) record of daily flows at 8 separate gaging stations would require a spectacularly large number of individual comparisons with threshold values. It is best computerized. Similarly, one candidate system for the above basin might have 5 stations monitoring 3 water quality parameters each, with typically six means assigned to each system element (parameter-station pair). The computation of availability and survivability would thus require the generation and solution of 30 transition matrices consisting of 64 elements each. Thus, as a minimum, the computer programs must be capable of computing the preliminary and final aspects of the interaction between the basin and the surveillance system, and of computing the reliability engineering aspects.

In addition, a relatively complete analytical program can be achieved by including coding to evaluate total cost and perform the final division of total cost by system effectiveness to yield the cost-effectiveness of the candidate.

The computer programs described in this section reflect these considerations.

DESCRIPTION OF DESIGN METHODS

The design methods can be thought of in terms of six basic task activities that encompass the processes and decisions suggested by Figure 12. Figure 27 shows the task flow of system design. As indicated, the modeling of the river basin can be done essentially off-line with respect to the system design. The task flow can be entered at either of two points. The first entry point is used when the designer's objective is to evaluate either an entirely new surveillance

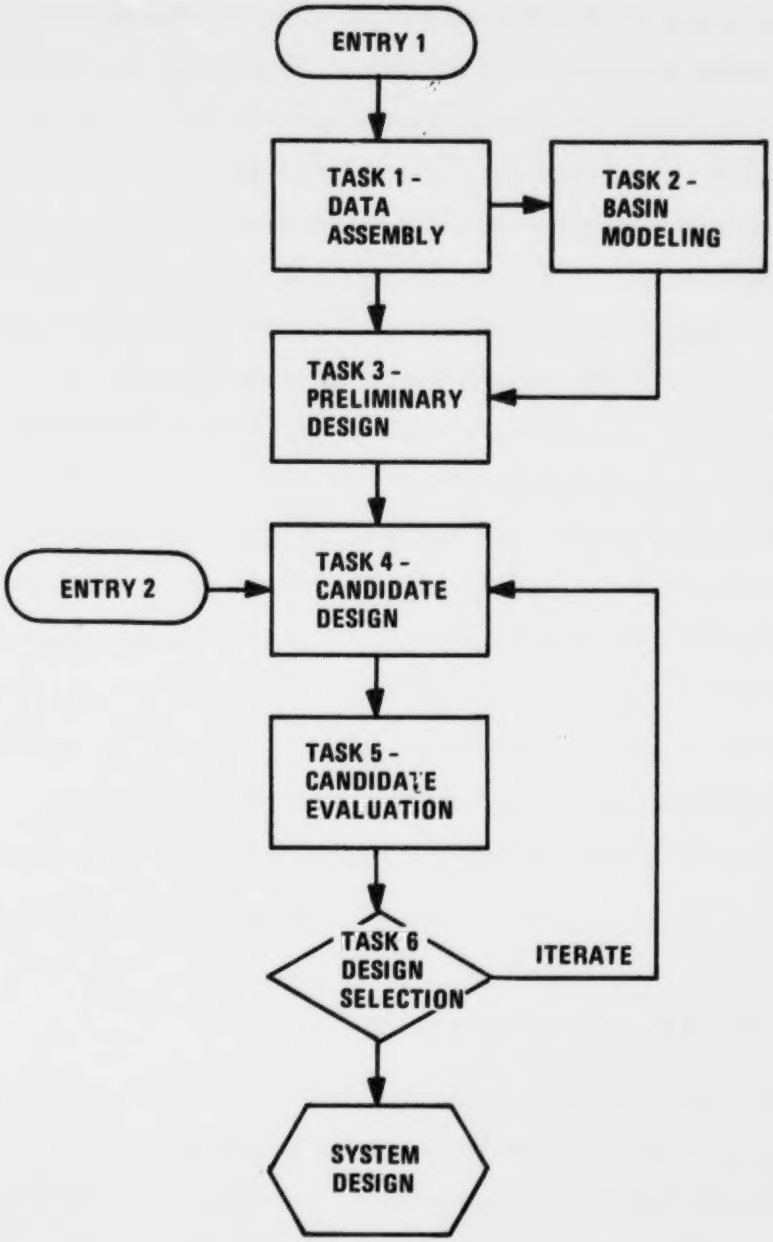

ENTRY 1
TASK 1 - DATA ASSEMBLY
TASK 2 - BASIN MODELING
TASK 3 - PRELIMINARY DESIGN
ENTRY 2
TASK 4 - CANDIDATE DESIGN
TASK 5 - CANDIDATE EVALUATION
TASK 6 DESIGN SELECTION
ITERATE
SYSTEM DESIGN

Figure 27. Design Task Flow Diagram

system or an existing one developed with another design approach. The second entry point is appropriate when the designer wishes to evaluate the effects of incremental improvements in an existing or candidate system, one for which the earlier task results are still valid. A third design objective might be the evaluation of an existing surveillance system on the basis of new information about the river basin. In this third case, the river basin model must be revised and the first entry point is used.

Task 1 - Data Assembly

The first step is the gathering of basic data descriptive of the river basin, of the water quality standards and of the surveillance methods. A full description of the necessary stream quality, stream characteristics, and effluent data required may be found in [3]. Assuming that the designer intends to use the computerized design methods detailed later in this section, [7] and [18] are useful in determining the data needs of the computerized basin model. The required information on surveillance methods is that necessary to fully characterize the candidates to be evaluated. The system characteristics are summarized in Table 4. Data on the indicated characteristics should be collected early in the design project during Task 1.

In addition, two essential determinations should be made during Task 1. Since the planned system duration (see Section IV) is always an externally imposed constraint on system design, an early determination of system duration should be made. At the same time, the designer must choose the water quality parameters to be considered in the design analysis. The decision is crucial, since it affects the evaluation of cost-effectiveness. A parameter included in the analysis, but never sampled, may cause a reduction in system effectiveness.

Table 4. SUMMARY OF SYSTEM CHARACTERISTICS

	Task 1		Task 4
System Characteristic	Input Data	Input Decision	Design Variable
■ Cost			
● Acquisition	X		
● Maintenance	X		
● Operating	X		
● Residual (Value)	X		
● Organization	X		
■ Availability			
● Unit Reliability (λ)	X		
● Unit Maintainability (μ)	X		
● Configuration			X
■ Survivability			
● Unit Survivability (λ)	X		
● Configuration			X
■ Capability			
● Location			X
● Sampling Rate			X
● Scheduled Maintenance			X
● Calibration Accuracy	X		
● Precision	X		
■ Nominal Characteristics			
● Parameters Considered		X	
● Segments Monitored			X
● Parameters Monitored			X
● System Duration		X	

Thus, a system designer must weigh the goals of his system in selecting the set of parameters to be analyzed. In general, the water quality standards to be enforced with the system will provide a guideline, listing specific parameters for enforcement.

Task 2 - Basin Modeling

Task 2 calls for the calibration of a mathematical model descriptive of the river basin under consideration. It is assumed in this report that the designer will employ RIBAM (see Section IV and Appendix A), a computerized basin model. Detailed information on the calibration of RIBAM using the Task 1 data inputs may be found in [7]. Additional useful guidance may be found in the User Handbook of [3].

In summary, Task 2 activities include: 1) identification of major point sources or groups of sources (impact nuclei), 2) selection of the basin segmentation scheme, and 3) preparation of the Standard Data Deck for the design conditions. The procedure is accomplished using the stand-alone version of RIBAM.

Should the designer choose to use some other basin model, either computerized or manual, the activities required to calibrate the model can be expected to be similar to those of RIBAM. Thus, the RIBAM calibration process serves as a useful guide to Task 2.

Task 2 can, of course, be done externally to the design process. RIBAM was developed for river basin planning purposes, not surveillance system design. It may be anticipated that many of the activities required in Task 1 and 2 will already have been accomplished when the monitoring system design project begins. One of the objectives in making use of a computerized model is the realization of such "spin-off" benefits.

Task 3 - Preliminary Design

The objective of Task 3 is the development of information to allow rational selection of candidate surveillance systems. That information includes: 1) the set of preferred sampling locations, 2) a measure of the preference for sampling at each of those locations, and 3) data on the temporal variability of water quality at those locations.

The preferred sampling location is the point in each reach of the basin where there is the greatest likelihood of a violation for each parameter. That point is shown in [3] to correspond approximately to the location of the expected worst conditions in each segment as determined by the river basin model. Table 5 indicates the assumed location for each category of water quality parameter.

Table 5. PREFERRED SAMPLING LOCATION BY PARAMETER CATEGORY

Category	Preferred Sampling Location
Conservative	Any point in segment
Non-Conservative, non-coupled	Head of segment
Non-Conservative, coupled ("Not to exceed" threshold)	Point of maximum value in segment
Non-Conservative, coupled ("Not less than" threshold)	Point of minimum value in segment

The relative preferrence for monitoring at each preferred location is the expected number of violations having upstream boundaries in the segment during the planned system duration, n_v^{**}. The expected number is computed from estimates of T_0^{**} and T_1^{**} using equation (21).

Use of n_v^{**} as a measure of preferrence for monitoring a segment constitutes a shift from the approach developed in [3]. The previous approach was to compute a measure (α) of the probability of violation (π_v) in the segment and select those segments with high α (high π_v) for surveillance. The probability of violation in a segment is not of direct use in attempting to maximize E_{sys} (equation (15)), since segments that are nearly always in a violation state will have a high probability of violation, but a small n_v**. Similarly, those segments with low probability of violation would also have a small n_v**, since they would tend to always be in a non-violation state. Thus, a better strategy for the selection of segments to monitor is to choose those segments with large n_v**, no matter what the probability of violation.

It is interesting to note that this result, derived in the context of statistical decision theory, is similar to a central concept of information theory. That concept can be stated generally as: "the more likely an event is, the less information is conveyed us by the knowledge of its actual occurence." [19] Thus, there is little information to be gained from monitoring segments in which there is a high probability of being in one of the states. The segments from which the most information may be gained from monitoring are those in which the greatest variability, i.e. the largest n_v**, exists.

Replacement of α with n_v** has an additional advantage; it eliminates the need to assume a gaussian distribution of the water quality parameter. The assumption of a distribution was necessary to the estimation of the probability of violation [3]. While the use of the gaussian assumption appears to be reasonably sound in this case, the elimination of any assumption is welcome in an engineering method.

Selection, in Task 4, of the sampling rates for monitoring is done with the guidance of Figure 5, developed in [3]. The necessary inputs to use of the sampling effectiveness rating curves are T_0 and T_1. For the present case, it is sufficient to approximate these with the T_0** and T_1** used in estimation of n_v**.

Task 4 - Candidate Design

The fourth task is the focus of the design process. Based on the preliminary design data supplied by the computer in Task 3, the system designer must design one or more candidate systems. Using the information on n_v** computed in Task 3, the first step is the choice of segments and parameters to be monitored. For each parameter to be monitored in each reach of the basin, the system designer must then specify:

Sampling Location

Sampling Rate

Sampling (calibration) Accuracy

Sampling Precision

Configuration of Means Used in Sampling

Maintenance Schedule

Selection of each of these requires a careful balancing of such factors as the resources available to the designer, the characteristics of those resources, the external constraints of access to the river and legal requirements, and the practical limitations of manpower and equipment scheduling. It is assumed that the system designer is capable of performing all the necessary design functions to assure that the nominal system characteristics specified can be achieved with the equipments and schedules specified.

Specification of sampling location requires analysis of both the preferred location computed in Task 3 and the ability to actually sample at that location. Another factor to consider is the grouping of monitoring of several parameters at the same site, perhaps different from the preferred location for each.

Sampling rate is based on the effectiveness indicated for a given rate using the T_0** and T_1** with Figure 5. Also affecting sampling rate are the sampling capacity of the equipment proposed and the scheduling of equipment and personnel.

The accuracy and precision to be achieved by each system element (parameter-segment pair monitored) is estimated as the overall error expected for the set of means in the element configuration, when working as intended. (Any other condition is considered a failed state.)

Task 5 - Candidate Evaluation

During Task 5, the methods developed in Section VI are applied to the candidate designs prepared in Task 4. Each candidate is evaluated for total cost, total effectiveness and the cost-effectiveness ratio. Intermediate results, such as availability, survivability and capability, may be retained for guidance in iteratively improving candidates.

Task 6 - Design Selection

Selection of the final system design is performed in Task 6 by comparison of the Task 5 evaluation results with predefined selection criteria in three areas: cost, effectiveness, and cost-effectiveness ratio. If none of the candidates satisfy the selection criteria or if it is desired to improve on particular candidates, the designer may choose to return to Task 4. In doing so, the evaluation data may be used to guide the development of new or improved candidates. For example, low values of capability may indicate a need for improvement in the nominal system characteristics, such as sampling frequency or reaches sampled. Poor survivability or availability may call for improvement of the means employed or incorporation of redundancies in the system. It should be pointed out here that the most cost-effective system is that system with the least cost per unit effectiveness, even though that value may be several times the true cost of the system.

OVERVIEW OF COMPUTER PROGRAMS

The monitoring system design analysis computer program consists of a main program and 33 subprograms. The relationships among the subprograms are diagrammed in Figure 28. As indicated in the figure, the coding that constitutes the analysis program comes from three different sources. The majority of the programming has been prepared by Raytheon OES specifically for the design analysis project. Other sections are taken, essentially intact, from RIBAM, the river basin model developed by Raytheon OES for the EPA. (See Section IV and [7].) International Mathematical and Statistical Libraries, Inc. (IMSL) has provided specific subprograms that perform general mathematical operations, such as curve fitting and solution of systems of linear equations. (See Acknowledgements.)

The program coding adopted from RIBAM is computationally identical with that found in the stand-alone version of RIBAM. The major change has been the elimination of the printed output from those subprograms. It is assumed that the Standard Data Deck used for system design analysis will have been calibrated using the stand-alone version of RIBAM. Thus, there is no need for printed output from the model portion of the design analysis program.

The organization of the main program reflects the basic computational sequence necessary in the evaluation of a monitoring system design. Figure 29 is a flowchart of the overall design analysis program. The initial step is a description of the natural (river) system to be monitored. This information includes the water quality parameters under consideration (not necessarily those monitored), the physical description of the river basin (tributaries, junctions, reaches, flows, etc.), the point-source loads (location, quantity, parameters, etc.), the reaction and decay rates, the relationships among the flows in individual reaches

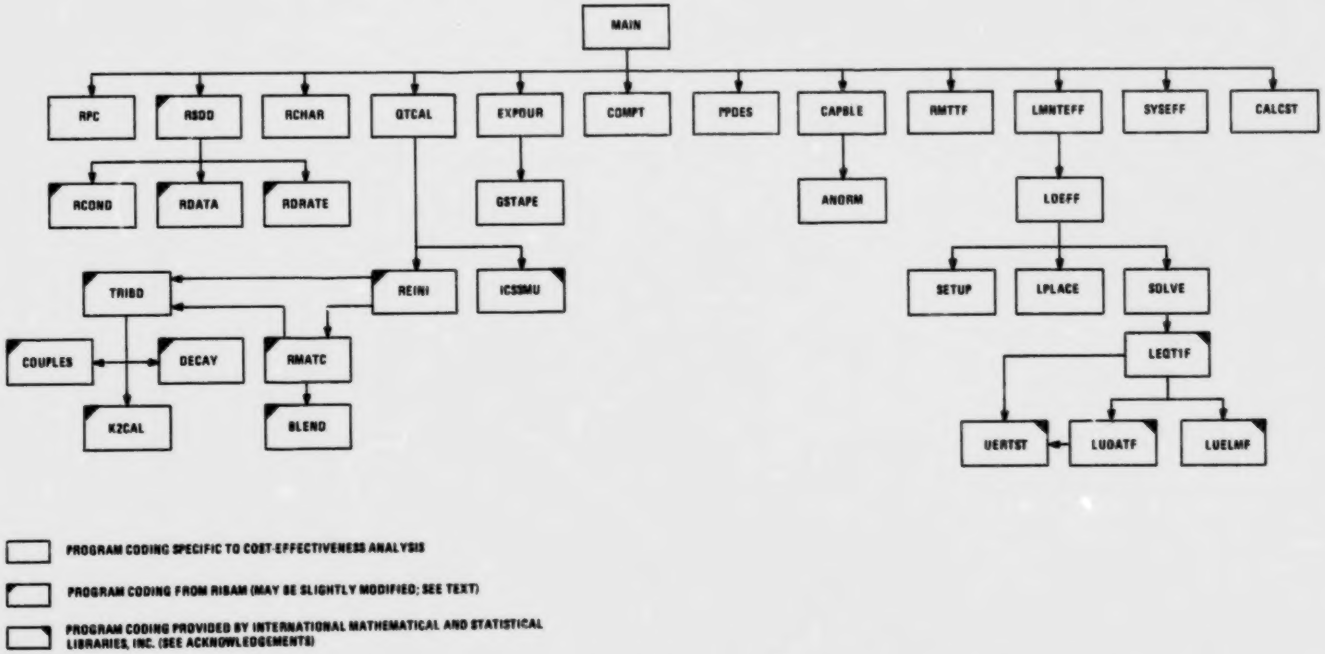

MAIN
RPC
RSDD
RCHAR
QTCAL
EXPOUR
COMPT
PPDES
CAPBLE
RMTTF
LMNTEFF
SYSEFF
CALCST
RCOND
RDATA
RDRATE
GSTAPE
ANORM
LOEFF
TRIBD
REINI
ICSSMU
SETUP
LPLACE
SOLVE
COUPLES
DECAY
RMATC
LEQTIF
K2CAL
BLEND
UERTST
LUDATF
LUELMF
PROGRAM CODING SPECIFIC TO COST-EFFECTIVENESS ANALYSIS
PROGRAM CODING FROM RIBAM (MAY BE SLIGHTLY MODIFIED; SEE TEXT)
PROGRAM CODING PROVIDED BY INTERNATIONAL MATHEMATICAL AND STATISTICAL LIBRARIES, INC. (SEE ACKNOWLEDGEMENTS)

Figure 28. Program Organization

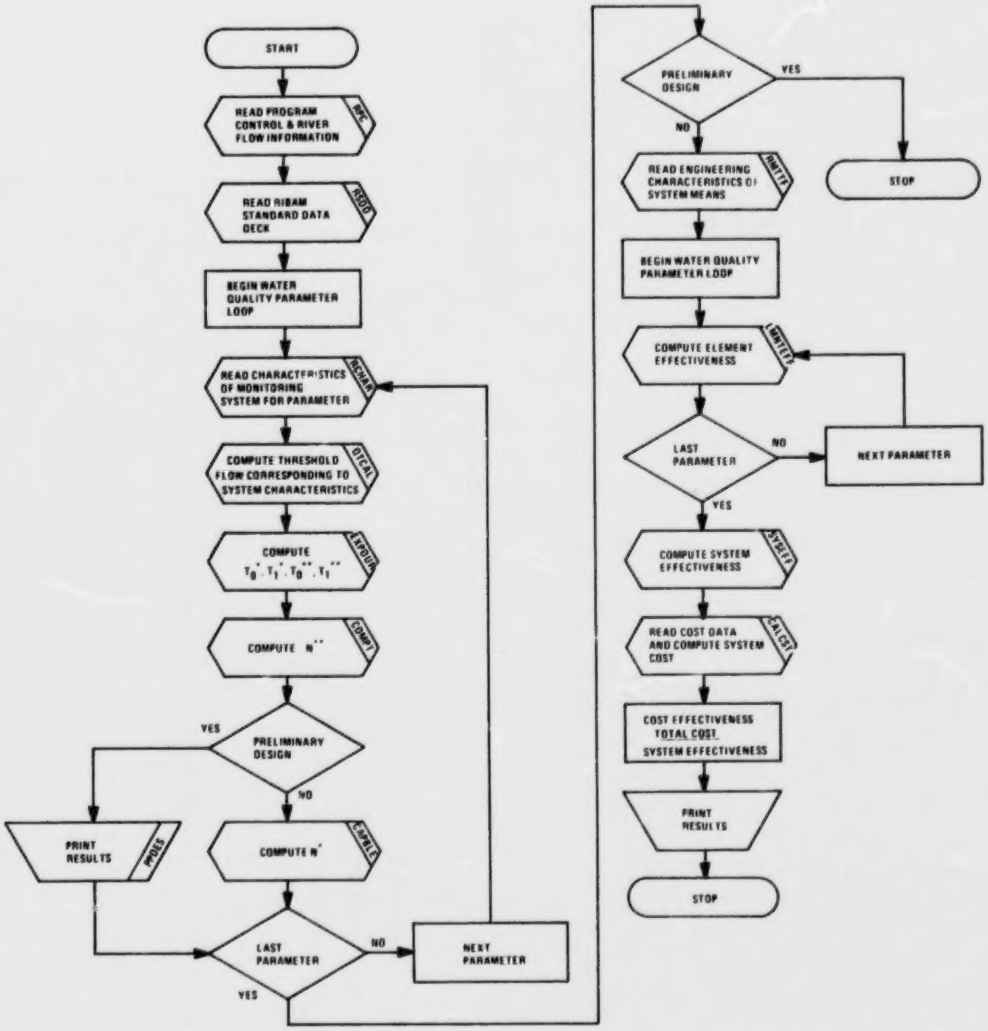

START
READ PROGRAM CONTROL & RIVER FLOW INFORMATION
RPC
READ RIBAM STANDARD DATA DECK
RSDD
BEGIN WATER QUALITY PARAMETER LOOP
READ CHARACTERISTICS OF MONITORING SYSTEM FOR PARAMETER
RCHAR
COMPUTE THRESHOLD FLOW CORRESPONDING TO SYSTEM CHARACTERISTICS
QTCAL
COMPUTE $T_0^*, T_1^*, T_0^{**}, T_1^{**}$
EXPOUR
COMPUTE N^{**}
COMPT
PRELIMINARY DESIGN
YES
NO
PRINT RESULTS
PPDES
COMPUTE N^*
CAPBLE
LAST PARAMETER
NO
YES
NEXT PARAMETER
PRELIMINARY DESIGN
YES
NO
STOP
READ ENGINEERING CHARACTERISTICS OF SYSTEM MEANS
RMTTF
BEGIN WATER QUALITY PARAMETER LOOP
COMPUTE ELEMENT EFFECTIVENESS
EMNTEFF
LAST PARAMETER
NO
YES
NEXT PARAMETER
COMPUTE SYSTEM EFFECTIVENESS
SYSEFF
READ COST DATA AND COMPUTE SYSTEM COST
CALCST
COST EFFECTIVENESS = $\frac{\text{TOTAL COST}}{\text{SYSTEM EFFECTIVENESS}}$
PRINT RESULTS
STOP

Figure 29. Top Level Program Flowchart

and those recorded by USGS gaging stations, and the range of flows to be considered for design purposes. The majority of the information is provided by the previously calibrated RIBAM Standard Data Deck. Using this information, a sequence of computations must be performed for each water quality parameter under consideration. The objective of the computations is either the evaluation of the capability of each system element, as defined in Section VI or the development of the preliminary design data. For each parameter, the nominal characteristics and the factors directly affecting capability must be supplied to the design analysis program. Using the approach developed in [3], threshold flows are computed, corresponding to the threshold concentrations specified in the stream standards. The threshold flow values are then compared with a long record of actual USGS gaging station observations to derive expected durations of violation and non-violation. The expected number of violations (n_v^{**}) and of detected violations (n_d^*) may then be computed, the latter using information on sampling interval and observational errors. For preliminary design, the program terminates at this point. Having completed the computation of system capability for each water quality parameter under consideration, attention is turned to the engineering aspects of the design analysis, if final design analysis is required. The engineering characteristics of the individual system means (mean survival times, mean failure times, mean repair times) are described. Using these data, the survivability and availability of each system element may be computed from information on the organization of the means in the element. Combining survivability and availability with the previously computed capability yields the element effectiveness. System effectiveness is then computed from element effectiveness and the expected number of violations. System cost is computed next, from information on the component costs. Finally, cost and effectiveness are combined to yield the cost-effectiveness index.

The reader is referred to Appendix E for details of the program development.

In the following paragraphs, the overall function of the main program and each subprogram is summarized.

MAIN - The main program provides overall sequencing of data input and computation. With one exception, no computations are performed by MAIN directly. The single exception is the computation of the total system cost-effectiveness (equation (7)).

RPC - Subroutine RPC reads data on the water quality parameters to be included, planned system duration, range of river flows, and the relationship of the river reaches to the USGS gaging stations.

RSDD - Subroutine RSDD consists of the coding from the RIBAM main program that reads the RIBAM Standard Data Deck. The echo-printing of the input data has been deleted, as have all other functions of the RIBAM main program. RSDD calls the RIBAM Subroutines RCOND, RDATA, RDRATE [3].

RCOND - Subroutine RCOND reads the headwater concentration data from the Standard Data Deck for all parameters being simulated. It is identical to the RIBAM version, except for deletion of echo-printing [3].

RDATA - Subroutine RDATA reads the point-source concentration data from the Standard Data Deck. It is identical to the RIBAM version, except for deletion of echo-printing [3].

RDRATE - Subroutine RDRATE reads the reaction rate data for non-conservative parameters being simulated from the Standard Data Deck. It is identical to the RIBAM version, except for deletion of echo-printing [3].

RCHAR - Each time Subroutine RCHAR is called it reads in a set of data describing the characteristics of the system related to system capability for the parameter under consideration (see Appendix F).

QTCAL - Subroutine QTCAL uses the RIBAM subroutines REINI, TRIBD, COUPLES, DECAY, K2CAL, RMATC and BLEND, and the IMSL subroutine ICSSMU to compute the threshold flows in each reach for the parameter under consideration (see Appendix E).

REINI - Subroutine REINI initializes the concentration for the parameter being computed in all headwater stretches and initializes flows in all headwater stretches. It calls TRIBD for each headwater stretch and repeats until all headwater stretches have been considered. It stores the concentrations at the end of the headwater stretch for the parameter being computed. It then calls RMATC for each junction and repeats until all junctions have been considered. All printed output and calls to output subroutines have been deleted from the RIBAM version [3].

TRIBD - Subroutine TRIBD computes physical parameters for each reach. It computes the concentration at the head of each reach for the parameter being computed. After all effluent source inputs have been added at the head of each reach, TRIBD computes the concentration at that point for the parameter in concern. It calls DECAY, if the parameter is non-conservative, non-coupled. If the parameter is non-conservative, coupled, it calls COUPLES. It is identical to the RIBAM version, except for deletion of printed output [3].

DECAY - Subroutine DECAY computes the decay of non-conservative, non-coupled parameters from the head of each reach to the end of the reach. It is identical to the RIBAM version [3].

COUPLES - Subroutine COUPLES divides each reach into ten subreaches of equal length and computes the concentration of the non-conservative, coupled parameters at the end of each subreach. It then finds the maximum and minimum subreach concentrations and the river mile of the end of the subreach where they occur. It is identical to the RIBAM version [3].

RMATC - Subroutine RMATC determines which headwater stretches enter a junction and which stretch is formed as a result of a junction. It then calls BLEND and TRIBD sequentially. It is identical to the RIBAM version [3].

BLEND - Subroutine BLEND computes the flow at the beginning of a downstream stretch formed by the junction of upstream stretches and computes the concentration of parameters at the beginning of the downstream stretch. It is identical to the RIBAM version [3].

K2CAL - Subroutine K2CAL obtains a value for average depth at each reach from one of two options. It then computes the reaeration coefficient for each reach from one of three options and adjusts values of reaeration coefficient for temperature dependency. It is identical to the RIBAM version [3].

ICSSMU - Subroutine ICSSMU performs a cubic spline curve fit on the five concentration versus flow curves computed using the RIBAM subroutines for each reach. QTCAL then uses the output of ICSSMU to compute the threshold flow for each reach. It is an IMSL library subroutine [20].

EXPDUR - Subroutine EXPDUR computes the expected durations: T_0^*, T_1^*, T_0^{**}, and T_1^{**}, using the threshold flows computed in QTCAL and actual historical stream flow data supplied by Subroutine GSTAPE. The subroutine contains very detailed logic to identify the spatial range of violations and to deal with stream junctions (see Appendix E).

GSTAPE - Subroutine GSTAPE is intended to provide the USGS gaging station data to EXPDUR in the proper form. In general, the USGS data are available from the federal government on magnetic tape. Because the interaction of a mag tape written by the USGS computer with the user's computer facility is determined by facility type, no general purpose subprogram can be prepared. Information is provided in Appendix F to guide the user in the preparation of a subroutine satisfying the functional requirements of GSTAPE.

COMPT - Subroutine COMPT performs two functions. First, it computes n_v^{**} from T_0^{**} and T_1^{**} (equation (21)). Then, it scans the T*'s for zero values and sets a flag accordingly. The flag is used in Subroutine CAPBLE to select the computational procedure used to evaluate n_v^*.

PPDES - Subroutine PPDES performs the simple task of formating and printing the information required for preliminary design.

CAPBLE - Subroutine CAPBLE computes n_d^* from the values of T_0^* and T_1^* supplied by EXPDUR and from the adjusted value for Δ_e (equation (40)). The computation is performed according to the approximate formulation presented in Section VI. Subroutine CAPBLE calls the function subprogram ANORM to supply values for the cumulative normal distribution (equation (37)).

ANORM - Function ANORM provides the calling program with the approximate value for the cummulative normal distribution with zero mean and unity standard deviation. The value is obtained by linear interpolation between tabular values for the cummulative distribution.

RMTTF - Subroutine RMTTF reads the data describing the engineering reliability, maintainability, and survivability characteristics of the individual means that may be included in the monitoring system.

LMNTEFF - Subroutine LMNTEFF computes the element effectiveness as the product of capability, availability and survivability (equation (20)). Capability is provided by Subroutine CAPBLE. Availability and survivability are computed by a call to Subroutine LDEFF.

LDEFF - For each system element, Subroutine LDEFF reads data describing the organization of the means used to perform the sampling of the element. It then uses Subroutines SETUP, LPLACE and SOLVE to setup the transition matrix and compute the survivability (LPLACE) or availability (SOLVE). The process is iterated until all system elements have been evaluated.

SETUP - Subroutine SETUP is used to generate the transition matrix using the element configuration (from LDEFF) and the means engineering data (from RMTTF). SETUP is used to generate either the survivability or the availability transition matrices (equations (25) and (28); also see Appendix E).

LPLACE - Subroutine LPLACE performs the computations necessary to effectively evaluate the Laplace transforms necessary in the survivability calculation (see Appendix E, equations (101), (102) and (103)).

SOLVE - Subroutine SOLVE prepares the availability transition matrix for solution using gaussian elimination. It calls the LEQT1F to perform the gaussian elimination (see Appendix E).

LEQT1F - Subroutine LEQT1F is an IMSL library routine that solves a set of linear equations using gaussian elimination with equilibration and partial pivoting. [20] The subroutine calls LUDATF, LUELMF and UERTST.

LUDATF - Subroutine LUDATF is an IMSL library routine that performs matrix decomposition. The NXN matrix is decomposed into a lower triangular and an upper triangular matrix. LUDATF calls UERTST. [20]

LUELMF - Subroutine LUELMF performs the elimination portion of the solution procedure. It is an IMSL library subroutine. [20]

UERTST - Subroutine UERTST is an IMSL library subroutine that is used to generate error messages. [20]

SYSEFF - The subroutine SYSEFF is used to sum all the individual element effectivenesses and the expected number of violations, and to compute the total system effectiveness, E_{sys} (equation (15)).

CALCST - Using cost data supplied to it, Subroutine CALCST calculates the total system cost (equation (9)) by matching the costs of the individual means with the list of means included in the system.

PROGRAM OUTPUT

The printed output resulting from use of the surveillance system design program is dependent on the choice of option, either preliminary design or final design.

Selection of the preliminary design option will produce output of the form shown in Figure 30. For each parameter under design consideration, the computer will produce a reach-by-reach listing of the expected number of violations originating in the reach (n_v**) during the system duration, the expected duration of the violations (T_1**), the expected duration of non-violation states (T_0**), and the preferred monitoring location (x_m). In the example shown in Figure 30, the preliminary design output is for parameter 11. It can be seen that, in reach number 29, 114 violations can be expected over the system duration, with an

```
PARAMETER = 11

REACH NO.    EXP. NO. OF    EXP. DURATION OF    EXP. DURATION OF    PREF. SAMPLING
             VIOLATIONS     A VIOLATION         A NON-VIOLATION     LOCATION,R.M.

    1        5.88710E+01      0.                    3.10000E+01         88.0
    2        5.88710E+01      0.                    3.10000E+01         87.0
    3        5.88710E+01      0.                    3.10000E+01         72.0
    4        5.88710E+01      0.                    3.10000E+01         70.0
    5        5.88710E+01      0.                    3.10000E+01         62.0
    6        5.88710E+01      0.                    3.10000E+01         55.0
    7        5.88710E+01      0.                    3.10000E+01         47.0
    8        5.88710E+01      0.                    3.10000E+01         42.0
    9        5.88710E+01      2.10000E+01           1.00000E+01         37.0
   10        5.88710E+01      0.                    3.10000E+01         35.0
   11        5.88710E+01      0.                    3.10000E+01         12.0
   12        5.88710E+01      0.                    3.10000E+01          6.5
   13        5.88710E+01      0.                    3.10000E+01         54.4
   14        5.88710E+01      0.                    3.10000E+01         51.2
   15        5.88710E+01      0.                    3.10000E+01         48.8
   16        5.88710E+01      0.                    3.10000E+01         47.4
   17        5.88710E+01      0.                    3.10000E+01         44.8
   18        5.88710E+01      0.                    3.10000E+01         42.4
   19        5.88710E+01      0.                    3.10000E+01         36.8
   20        5.88710E+01      0.                    3.10000E+01         24.8
   21        5.88710E+01      0.                    3.10000E+01         31.0
   22        5.88710E+01      0.                    3.10000E+01         28.0
   23        5.88710E+01      0.                    3.10000E+01         25.0
   24        1.17742E+02      2.50000E+00           1.30000E+01         23.5
   25        5.88710E+01      0.                    3.10000E+01         21.5
   26        5.88710E+01      0.                    3.10000E+01         19.5
   27        5.88710E+01      0.                    3.10000E+01         18.5
   28        1.01389E+02      1.30000E+01           5.00000E+00         16.5
   29        1.14063E+02      1.00000E+00           1.50000E+01         15.5
   30        1.01389E+02      5.00000E+00           1.30000E+01         12.5
   31        5.88710E+01      0.                    3.10000E+01          4.5
   32        5.88710E+01      0.                    3.10000E+01         21.6
   33        5.88710E+01      0.                    3.10000E+01         19.8
   34        5.88710E+01      0.                    3.10000E+01         12.6
   35        5.88710E+01      0.                    3.10000E+01         10.8
   36        5.88710E+01      0.                    3.10000E+01          7.8
   37        5.88710E+01      0.                    3.10000E+01          3.8
   38        5.88710E+01      0.                    3.10000E+01          1.8
```

Figure 30. Typical Preliminary Design Output

average duration of 1 day and an average interval between violations of 15 days. The preferred sampling location in reach 29 is at river mile 15.5.

Choice of the final design option produces output typified by Figures 31 and 32. For each parameter under consideration, a reach-by-reach listing of capability, survivability, availability and element effectiveness is produced (Figure 31). For each parameter (parameter 17 in the example shown), the results of the effectiveness analysis are listed for each reach selected for monitoring in the candidate under consideration. Capability is computed according to equation (40), while survivability and availability are computed according to equations (27) and (30), respectively. The element effectiveness is the product of those three factors, as in equation (20). A final summary page follows (Figure 32),

```
PARAMETER NUMBER =  17

REACH NO. =   2 CAP =  2.57711E-04 SURV =  7.66156E-01 AVAIL =  9.68061E-01 ELEMENT EFF. =  1.91140E-04
REACH NO. =  18 CAP =  1.71128E-02 SURV =  9.35785E-01 AVAIL =  9.99801E-01 ELEMENT EFF. =  1.60107E-02
REACH NO. =  21 CAP =  2.66354E-02 SURV =  9.35785E-01 AVAIL =  9.99801E-01 ELEMENT EFF. =  2.49200E-02
REACH NO. =  36 CAP =  1.74748E-02 SURV =  9.35785E-01 AVAIL =  9.99801E-01 ELEMENT EFF. =  1.63494E-02
```

Figure 31. Typical Reach-by-Reach Analysis Print-out

```
 SYSTEM EFFECTIVENESS =  2.02066E-01

TOTAL COST =  1.70950E+05

COST/EFF. =  8.46011E+05
```

Figure 32. Typical Final Summary Page

listing total system effectiveness (equation (15)), total system cost (equation (9)) and the system cost-effectiveness (equation (7)). Thus, in the case shown, the total system effectiveness, E_{sys}, is 0.20 and the total cost, K_{sys}, is \$170,950. The result is a system cost-effectiveness of \$846,011/unit effectiveness.

Also available to the user is the echo-printing option. Under that option, selected data from the input deck are printed out for reference during analysis of the results (see Figures 33, 34, 35, 36 and 37). No option is available to echo-print the RIBAM Standard Data Deck, since it is assumed the designer will have listings available from the RIBAM calibration. The limitation on echo-printing is made to minimize program size; FORTRAN FORMAT statements place heavy requirements on storage.

The output shown in Figure 33 incorporates data input on the CONTROL and USGS cards described later in this section. The printout indicates, for example, that the sixth USGS gaging station in the basin has the ID number 3105500, is located in reach number 33 and is considered typical of the flows in reaches 32, 33 and 34.

```
DESIGN TYPE = F SYSTEM DUR. =   1.00 NO. OF MONTHS =   60 FLOW SCALING FACTORS =  1.0  5.0  2.0   .5   .3

STA. NO.      STA. I.D.      SEG. NO.    SEG. ASSOCIATION


   1           3091500          5         1 2 3 4 5-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
   2           3094000          7         6 7 8 910-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
   3           3098000         25        212223242526-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
   4           3099500         29        2728293031-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
   5           3103500         13        1314151617181920-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
   6           3105500         33        323334-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
   7           3107500         36        35363738-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
   8           3095500         11        1112-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
```

Figure 33. Typical Echo-Print of USGS Data Input

Figure 34 shows the result of echo-printing data from the CHAR cards described later in this section. The example shown in Figure 34 is for parameter 17. The candidate system under consideration will sample parameter 17 at four locations, reaches 2, 18, 21 and 36, as indicated by "T" under the "IMPL." heading. The station at reach 21 will be maintained according to the policy described by equation (34) (heading "MN. PLCY." = "T"), with no down time ("TUP" = 365. and "TDOWN" = 0.0). The water quality standards threshold ("CT") is 5 mg/l in the reach. Sampling will be done every 3.5 days ("DELTA") at river mile 30.6 ("IMPL. LOC."). The means used to sample the river has an accuracy ("EPSI") of 0.02 and a precision ("SEPSI") of 0.1.

The data input on the MTTF cards are echo-printed in the form shown in Figure 35, with the following correspondences:

MTTFS = λ for survivability
MTTFA = λ for availability
MTTRA = μ for availability.

Data on the detailed configurations of the system means input on the AVAIL and SURV cards are echo-printed in the formats shown in Figures 36 and 37. These

```
PARAMETER NUMBER =  17
REACH NO. IMPL.   MN. PLCY.   CT     DELTA   IMPL. LOC.   EPSI     SEPSI    TUP     TDOWN

     1     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     2     T         T       5.000   90.00     82.50       .020     .100  365.00    0.00
     3     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     4     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     5     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     6     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     7     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     8     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     9     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    10     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    11     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    12     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    13     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    14     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    15     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    16     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    17     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    18     T         T       5.000    7.00     36.80       .020     .100  365.00    0.00
    19     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    20     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    21     T         T       5.000    3.50     30.60       .020     .100  365.00    0.00
    22     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    23     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    24     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    25     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    26     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    27     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    28     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    29     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    30     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    31     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    32     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    33     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    34     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    35     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    36     T         T       5.000    7.00      4.00       .020     .100  365.00    0.00
    37     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    38     F         F       5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
```

Figure 34. Typical Echo-Print of System Characteristics Input

```
                         STATE 1 = OPERATING, STATE 2 = STAND-BY
MEANS NO..   MTTFS-1   MTTFS-2   MTTFA-1   MTTFA-2   MTTRA-1   MTTRA-2

    1          .20       .01      2.00      1.00     365.00    365.00
    2          .01       .01      2.00       .01     365.00    365.00
    3          .01       .01      2.00       .01     365.00    365.00
    4          .20       .01      4.00      2.00     365.00    365.00
    5          .02       .02      4.00       .10      52.00     52.00
    6          .20       .01      2.00      1.00     365.00    365.00
    7          .01       .01      2.00       .01     365.00    365.00
    8          .01       .01      2.00       .01     365.00    365.00
    9          .20       .01      4.00      2.00     365.00    365.00
   10          .20       .01      2.00      1.00     365.00    365.00
   11          .01       .01      2.00       .01     365.00    365.00
   12          .20       .01      4.00      2.00     365.00    365.00
   13          .20       .01      4.00      2.00     365.00    365.00
   14          .02       .02      4.00       .10      52.00     52.00
   15          .20       .01      2.00      1.00     365.00    365.00
   16          .01       .01      2.00       .01     365.00    365.00
   17          .20       .01      4.00      2.00     365.00    365.00
   18          .20       .01      4.00      2.00     365.00    365.00
   19          .20       .10      4.00      1.00     122.00    122.00
```

Figure 35. Typical Echo-Print of System Reliability Input

```
PARAMETER NUMBER =  17 ELEMENT DESIGN FOR AVAILABILITY
REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

    2         1            1         S 2S 3M19 -0 -0 -0 -0 -0 -0 -0
    2         2            1         M 1M 4P 3 -0 -0 -0 -0 -0 -0 -0
    2         3            2         M 6M 9P 2 -0 -0 -0 -0 -0 -0 -0
   18         1            1         S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
   18         2            1         M10M12P 3 -0 -0 -0 -0 -0 -0 -0
   18         3            2         M15M17P 2 -0 -0 -0 -0 -0 -0 -0
   21         2            1         M 1M 4P 3 -0 -0 -0 -0 -0 -0 -0
   21         3            2         M 6M 9P 2 -0 -0 -0 -0 -0 -0 -0
   36         1            1         S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
   36         2            1         M10M12P 3 -0 -0 -0 -0 -0 -0 -0
   36         3            2         M15M17P 2 -0 -0 -0 -0 -0 -0 -0
```

Figure 36. Typical Echo-Print of Availability Input Data

```
PARAMETER NUMBER = 17 ELEMENT DESIGN FOR SURVIVABILITY
REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

    2         1            1         S 2S 3M19 -0 -0 -0 -0 -0 -0 -0
    2         2            1         M 1M 4P 3 -0 -0 -0 -0 -0 -0 -0
    2         3            2         M 6M 9P 2 -0 -0 -0 -0 -0 -0 -0
   18         1            1         S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
   18         2            1         M10M12P 3 -0 -0 -0 -0 -0 -0 -0
   18         3            2         M15M17P 2 -0 -0 -0 -0 -0 -0 -0
   21         1            1         S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
   21         2            1         M 1M 4P 3 -0 -0 -0 -0 -0 -0 -0
   21         3            2         M 6M 9P 2 -0 -0 -0 -0 -0 -0 -0
   36         1            1         S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
   36         2            1         M10M12P 3 -0 -0 -0 -0 -0 -0 -0
   36         3            2         M15M17P 2 -0 -0 -0 -0 -0 -0 -0
```

Figure 37. Typical Echo-Print of Survivability Input Data

outputs essentially duplicate the card formats; the reader is referred to following portions of this section for a detailed explanation of those formats.

USE OF PROGRAMS

As described earlier in this section, the design analysis programs constitute an integral part of design Tasks 3 and 5. They provide the preliminary design data necessary to design of system candidates in Task 4 and they perform the cost-effectiveness analysis required for candidate selection in Task 6. In the following paragraphs, use of the design analysis programs is described first for preliminary design analysis and then for final design analysis.

Preliminary Design

Preliminary design analysis requires that the computer programs be supplied with the data listed in Table 6. As indicated in the table, each data item is associated with a data input card, with the entire set of cards constituting the preliminary design data deck (Figure 38). These cards are identical with those found in the "front-end" of the final design data deck described below.

As shown in Figure 38, the first card in the data deck is the CONTROL card. The format of the CONTROL card is shown in Figure 39. For preliminary design, a "T" (= .TRUE.) is placed in column 9. In columns 11-27, the water quality parameters to be modeled and those to be included in the effectiveness analysis are selected. Each column in the field corresponds to a parameter in the RIBAM model, with column 11 corresponding to parameter 1 and column 27 corresponding to parameter 17. Since the correspondence between parameter number and the actual water quality parameter may vary with RIBAM application, the relationship can not be detailed further (see Appendix A). Because many of the parameters modeled by RIBAM are non-conservative coupled parameters, it

Table 6. REQUIRED PRELIMINARY DESIGN INPUT DATA

Data Type	Data Card(s)	Units
Parameters to be modeled	CONTROL	N/A
Parameters included in effectiveness analysis	CONTROL	N/A
System duration	CONTROL	years
Length of USGS gaging station record	CONTROL	months
Flow scaling factors	CONTROL	N/A
USGS station ID numbers	USGS (1 ea. sta.)	N/A
Location of USGS stations	USGS (1 ea. sta.)	N/A
Stream segments associated with USGS stations	USGS (1 ea. sta.)	N/A
Basin description	RIBAM Standard Data Deck	N/A
Water quality standard threshold concentration	CHAR (1 ea. parameter and segment)	mg/l (except coliforms)

is frequently necessary to model more parameters than those to be included in the analysis. When a parameter is to be included in the analysis, a "2" is punched in the corresponding column. If a parameter must be modeled to satisfy RIBAM coupling requirements, but is not to be included in the analysis, a "1" is punched in the corresponding column. As shown in Figure 39, the system duration (years), the length of the USGS gaging station record (months) and the flow scaling factors selected by the system designer are also entered on the CONTROL card. Finally, the user indicates his preference for echo-printing by entering a "T" in column 70.

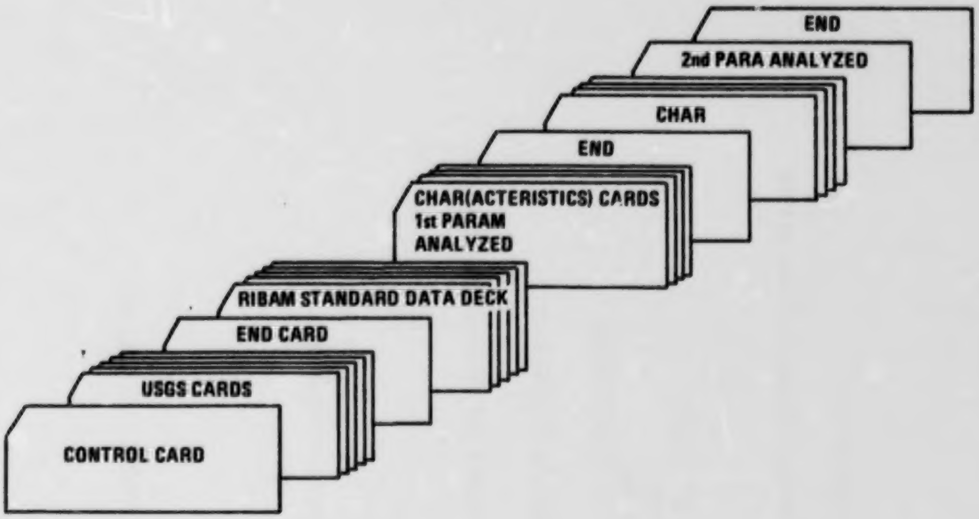

END
2nd PARA ANALYZED
CHAR
END
CHAR(ACTERISTICS) CARDS
1st PARAM
ANALYZED
RIBAM STANDARD DATA DECK
END CARD
USGS CARDS
CONTROL CARD

Figure 38. Preliminary Design Data Deck

The next set of cards in the data deck is the file of USGS cards. There is one card for each USGS flow gaging station in the basin used in the analysis. The format of the USGS card is shown in Figure 40. An arbitrary sequence or index number is entered in columns 9-10. The last eight digits of the ID number assigned by USGS to the station is entered in columns 13-20. Columns 22-23 contain the number of the stream reach in which the gaging station is located. Following in columns 25-80 are the two-digit reach numbers of each stream segment associated with the gaging station for computation of stream flow. The segment listed in columns 22-23 must be repeated in columns 25-80. The file of USGS cards is followed by a card with "END" punched in columns 1-3.

Following the USGS card file is the RIBAM Standard Data Deck. Details of the RIBAM Standard Data Deck may be found in [7], along with instructions for preparation.

The preliminary design data deck is terminated by one or more characteristics (CHAR) card files. One file is prepared for each parameter to be analyzed

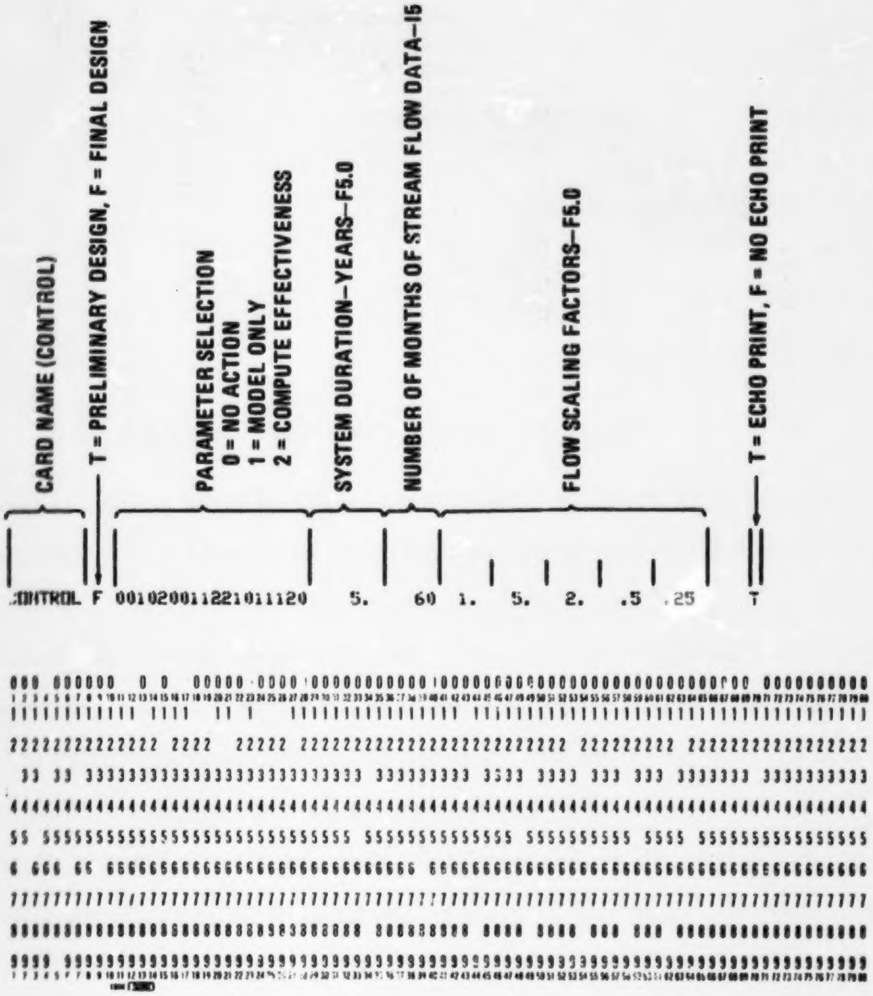

CARD NAME (CONTROL)
T = PRELIMINARY DESIGN, F = FINAL DESIGN
PARAMETER SELECTION
0 = NO ACTION
1 = MODEL ONLY
2 = COMPUTE EFFECTIVENESS
SYSTEM DURATION—YEARS—F5.0
NUMBER OF MONTHS OF STREAM FLOW DATA—I5
FLOW SCALING FACTORS—F5.0
T = ECHO PRINT, F = NO ECHO PRINT
CONTROL F 001020011221011120 5. 60 1. 5. 2. .5 .25 T

Figure 39. CONTROL Card Format

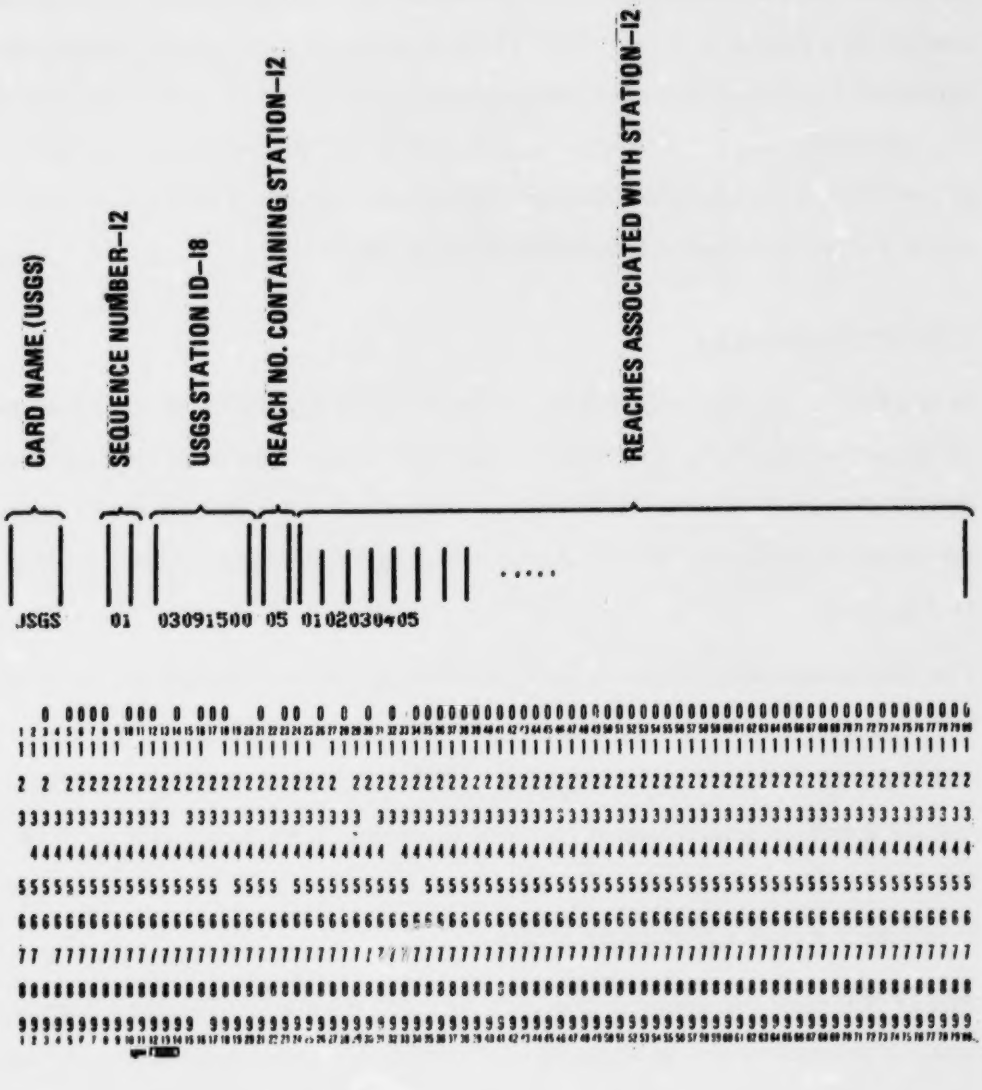

CARD NAME (USGS)
SEQUENCE NUMBER–I2
USGS STATION ID–I8
REACH NO. CONTAINING STATION–I2
REACHES ASSOCIATED WITH STATION–I2
USGS
01
03091500
05
0102030405

Figure 40. USGS Card Format

(2's in columns 11-27 of the CONTROL card). Each file contains one card for each reach in the basin. The CHAR card format is shown in Figure 41. The parameter number (numbers 1-17) is entered in columns 5-6 and the segment number in columns 7-8. Columns 11-20 contain the water quality standards threshold for the parameter in the segment. For purposes of preliminary design, the remainder of the CHAR card may be left blank, since those fields are descriptive of the candidate monitoring system element. Each file of CHAR cards for one parameter is terminated by an END card.

Final Design Analysis

In addition to the data required by preliminary design (Table 6), the final design requires the data listed in Table 7. The final design data deck for each candidate is prepared by adding information to the CHAR card file(s) and by appending additional card files. The composition of the final design data deck is illustrated in Figure 42.

The information added to the CHAR cards is entered in columns 9-10 and 21-80 (see Figure 41). If the candidate system includes monitoring of the parameter and segment indicated in columns 5-8 of the CHAR card, a "T" is punched in column 9 and the remainder of the card filled-in. If no monitoring is to be done, column 9 may be left blank or punched with an "F" and the remainder of the card is left as it was in preliminary design.

The MTTF card file contains one card for each means incorporated in the system. For convenience in analysis of a number of candidates sharing the same means, cards for means not incorporated in a given candidate may also be left in the file. Thus, only one MTTF file need be prepared for all the candidates. The format of the MTTF card is shown in Figure 43. The means number's is entered in columns 8-10. Following that, in 6 fields of 10 columns each, are:

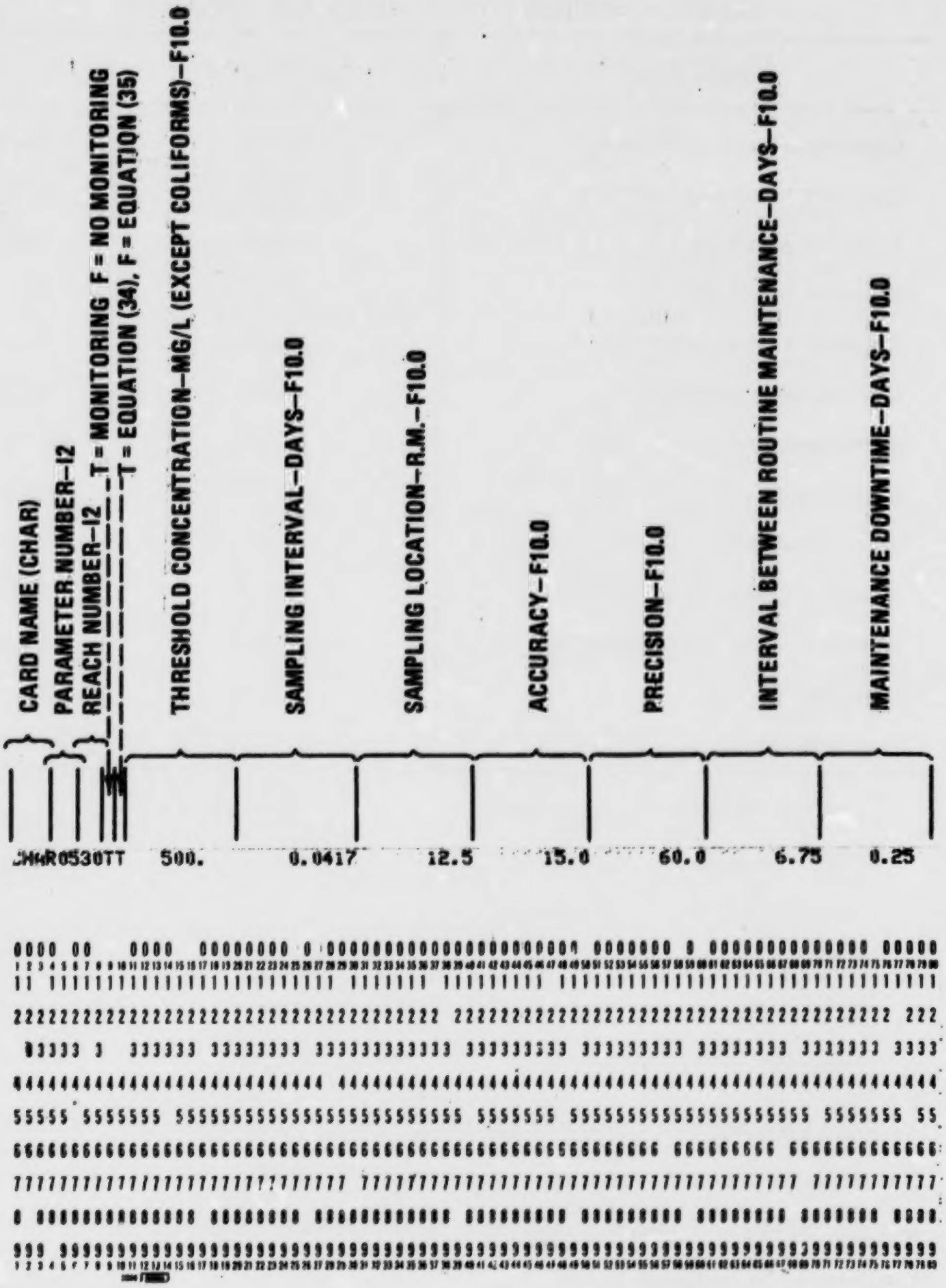

CARD NAME (CHAR)
PARAMETER NUMBER—I2
REACH NUMBER—I2
T = MONITORING F = NO MONITORING
T = EQUATION (34), F = EQUATION (35)
THRESHOLD CONCENTRATION—MG/L (EXCEPT COLIFORMS)—F10.0
SAMPLING INTERVAL—DAYS—F10.0
SAMPLING LOCATION—R.M.—F10.0
ACCURACY—F10.0
PRECISION—F10.0
INTERVAL BETWEEN ROUTINE MAINTENANCE—DAYS—F10.0
MAINTENANCE DOWNTIME—DAYS—F10.0
CHAR0530TT
500.
0.0417
12.5
15.0
60.0
6.75
0.25

Figure 41. CHAR Card Format

Table 7. REQUIRED FINAL DESIGN INPUT DATA

Data Type	Data Card(s)	Units
Element sampling interval	CHAR	days
Element sampling location	CHAR	RM
Element accuracy	CHAR	mg/l
Element precision	CHAR	mg/l
Element maintenance policy	CHAR	N/A
Maintenance schedule	CHAR	days
Survivability	MTTF	years^{-1}
Reliability	MTTF	years^{-1}
Maintainability	MTTF	years^{-1}
Element design (survivability)	SURV	N/A
Element design (availability)	AVAIL	N/A
Cost data-group	COSTG	$/sys. dur.
Cost data-means	COSTM	$/sys. dur.

λ for survivability in operation

λ for survivability in stand-by

λ for availability in operation

λ for availability in stand-by

μ for availability in operation

μ for availability in stand-by

It should be noted that these are the rates, not the mean times. Thus, a means that tends to fail in a repairable mode twice a year has a value of 2.0 entered in columns 31-40 and a means that tends to survive for ten years has a value of 0.1 entered in columns 11-20.

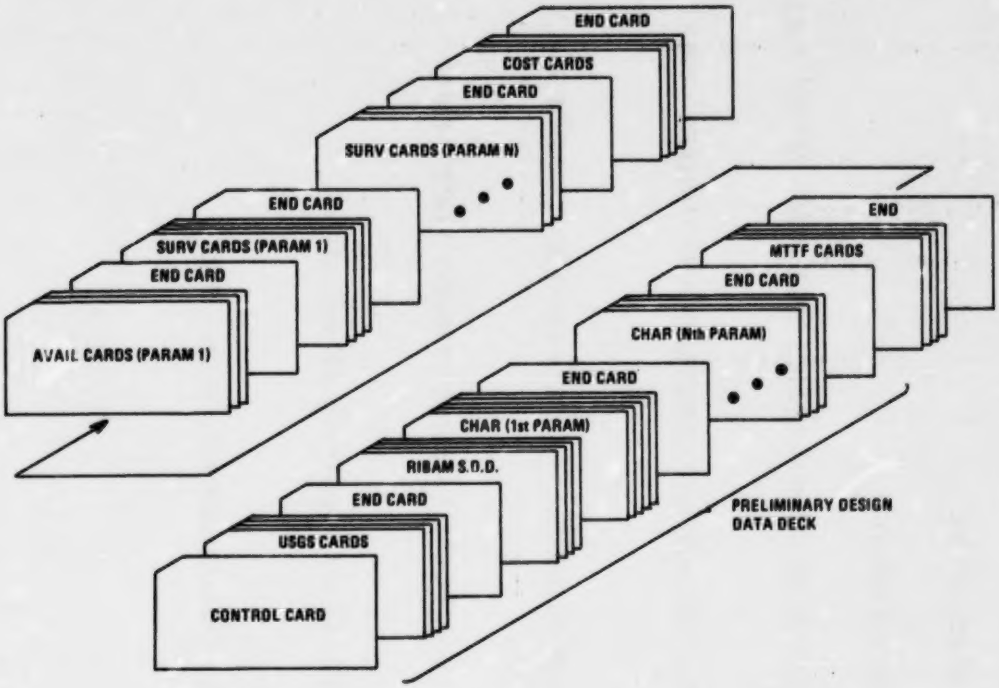

END CARD
COST CARDS
END CARD
SURV CARDS (PARAM N)
END CARD
SURV CARDS (PARAM 1)
END CARD
AVAIL CARDS (PARAM 1)
END
MTTF CARDS
END CARD
CHAR (Nth PARAM)
END CARD
CHAR (1st PARAM)
RIBAM S.O.D.
END CARD
USGS CARDS
CONTROL CARD
PRELIMINARY DESIGN DATA DECK

Figure 42. Final Design Data Deck

Following the MTTF file are paired files of AVAIL and SURV cards. There is one pair of files for each parameter included in the effectiveness analysis ("2" in columns 11-27 of the CONTROL card). Within each file are cards describing the functional configuration of system element for the associated category, either availability (AVAIL) or survivability (SURV). One card is prepared for each path in each system element (see Section VI). The segment number is entered in columns 8-9 (Figure 44) the parameter number is entered in columns 13-14, and the path number in columns 18-19. The normal operating status of the path is entered in columns 23-24. As described in Section VI, each element path or sub-path may be composed of means and other sub-paths. In addition, each sub-path may have one or more parallel sub-paths. This information is punched in

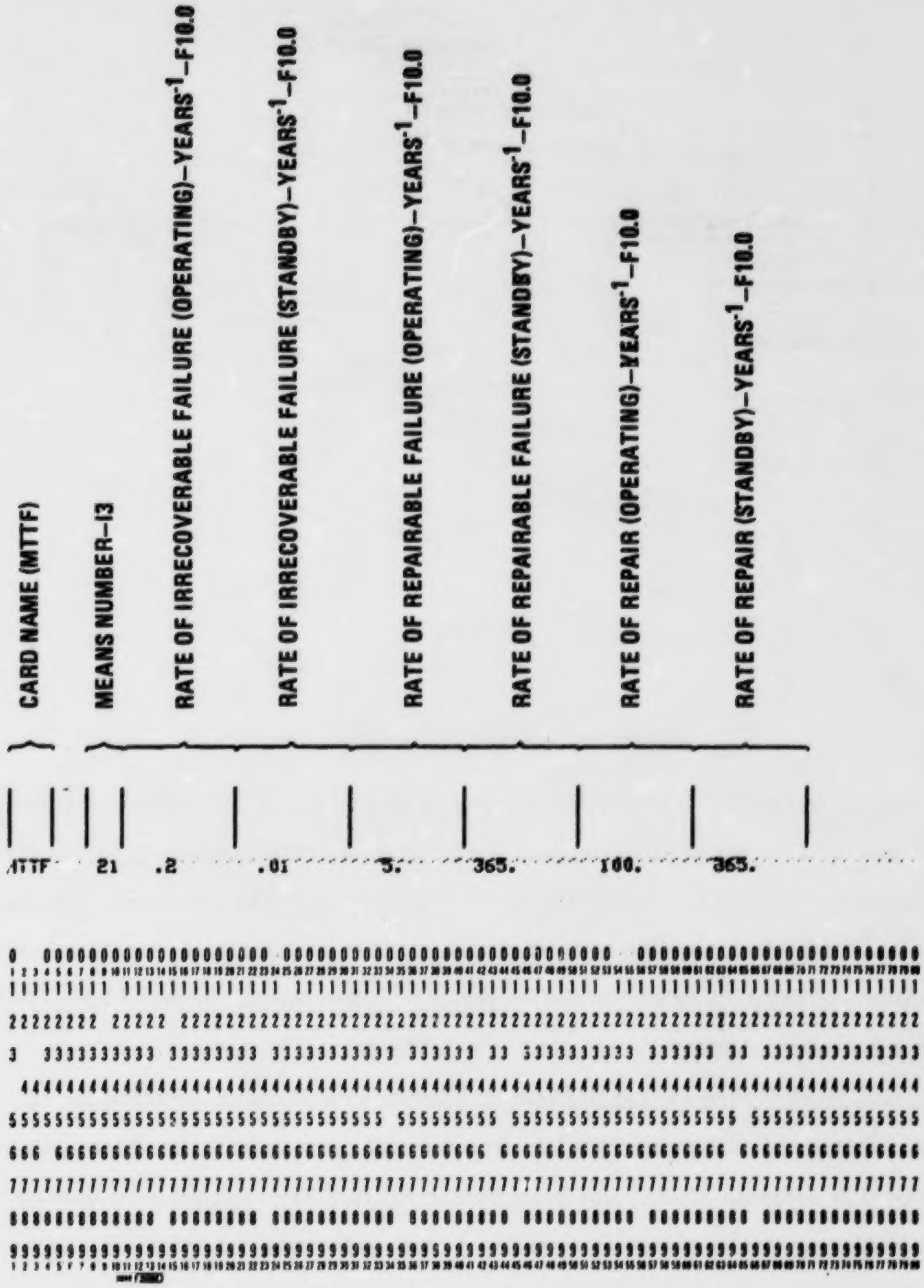

CARD NAME (MTTF)
MEANS NUMBER–I3
RATE OF IRRECOVERABLE FAILURE (OPERATING)–YEARS⁻¹–F10.0
RATE OF IRRECOVERABLE FAILURE (STANDBY)–YEARS⁻¹–F10.0
RATE OF REPAIRABLE FAILURE (OPERATING)–YEARS⁻¹–F10.0
RATE OF REPAIRABLE FAILURE (STANDBY)–YEARS⁻¹–F10.0
RATE OF REPAIR (OPERATING)–YEARS⁻¹–F10.0
RATE OF REPAIR (STANDBY)–YEARS⁻¹–F10.0
MTTF
21
.2
.01
5.
365.
100.
365.

Figure 43. MTTF Card Format

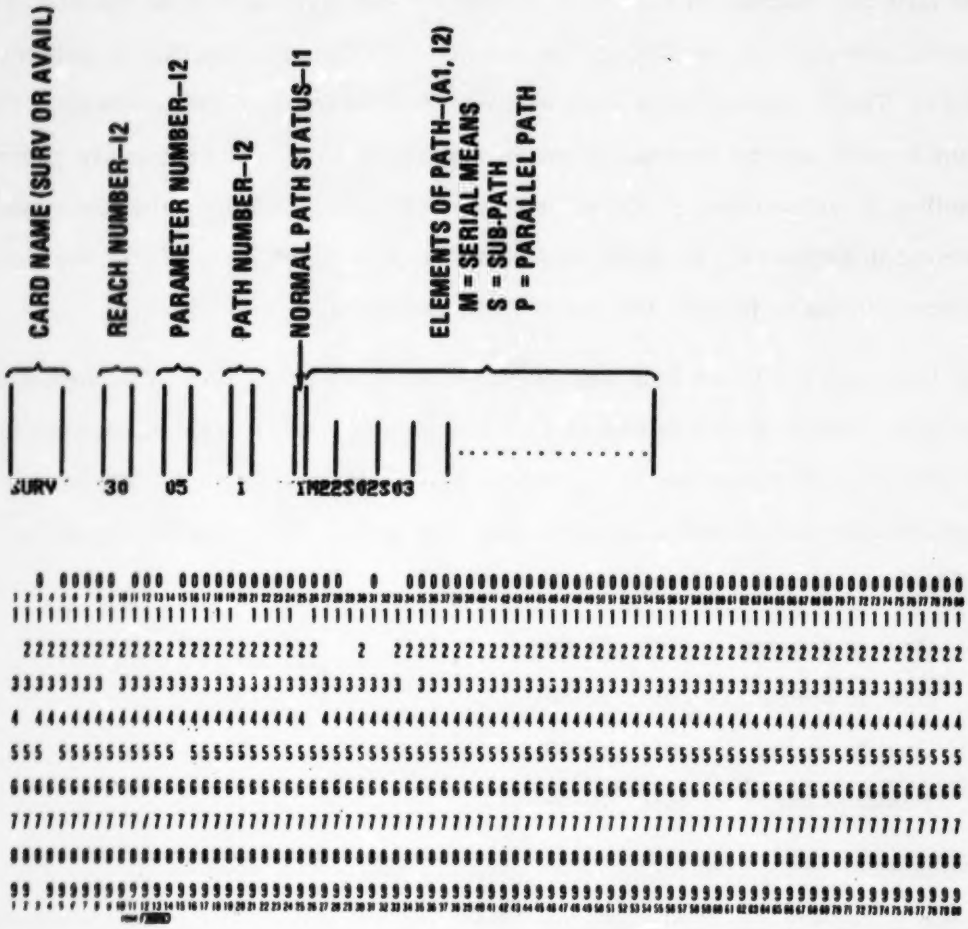

CARD NAME (SURV OR AVAIL)
REACH NUMBER–I2
PARAMETER NUMBER–I2
PATH NUMBER–I2
NORMAL PATH STATUS–I1
ELEMENTS OF PATH–(A1, I2)
M = SERIAL MEANS
S = SUB-PATH
P = PARALLEL PATH
SURV
30
05
1
1M22S02S03

Figure 44. AVAIL and SURV Card Format

columns 25–54 in fields of 3 columns. The first column in each field contains one of the following letters:

M - means

S - sub-path

P - parallel path

(blank) - terminate processing of card.

The next two columns of each field contain the two digit identifying number of the means, sub-path or parallel path associated with the path specified in columns 18-19. The 3-column fields must be filled in from left to right, since the first blank leading column terminates processing of the card. The cards are grouped together by parameter, as shown in Figure 42, with all paths of the same system element in sequence. Each file is terminated with an END card. See the demonstration case in Section VIII for several examples of these cards.

The last card file in the final design data deck is the COST file. The format of the COST card is shown in Figure 45. The type of cost analysis component is specified by entry of either G = group or M = means in column 5. The means or group number is entered in columns 6-10, as appropriate. Following, in fields of 10, from column 11 to column 50 are:

Cost to acquire - cols. 11-20
Cost to operate - cols. 21-30
Cost to maintain - cols. 31-40
Residual value - cols. 41-50

The number of the next higher level group is entered in columns 56-60. For group 1, the system level, columns 56-60 are left blank. If they are blank on any other card of the file, an error is sensed and processing terminated. As with the MTTF file, extraneous means and groups may be included in the file for convenience in analyzing a large number of candidates. Only those means specified in the AVAIL and SURV files are included in the cost estimate by the analysis programs. The file is terminated by an END card.

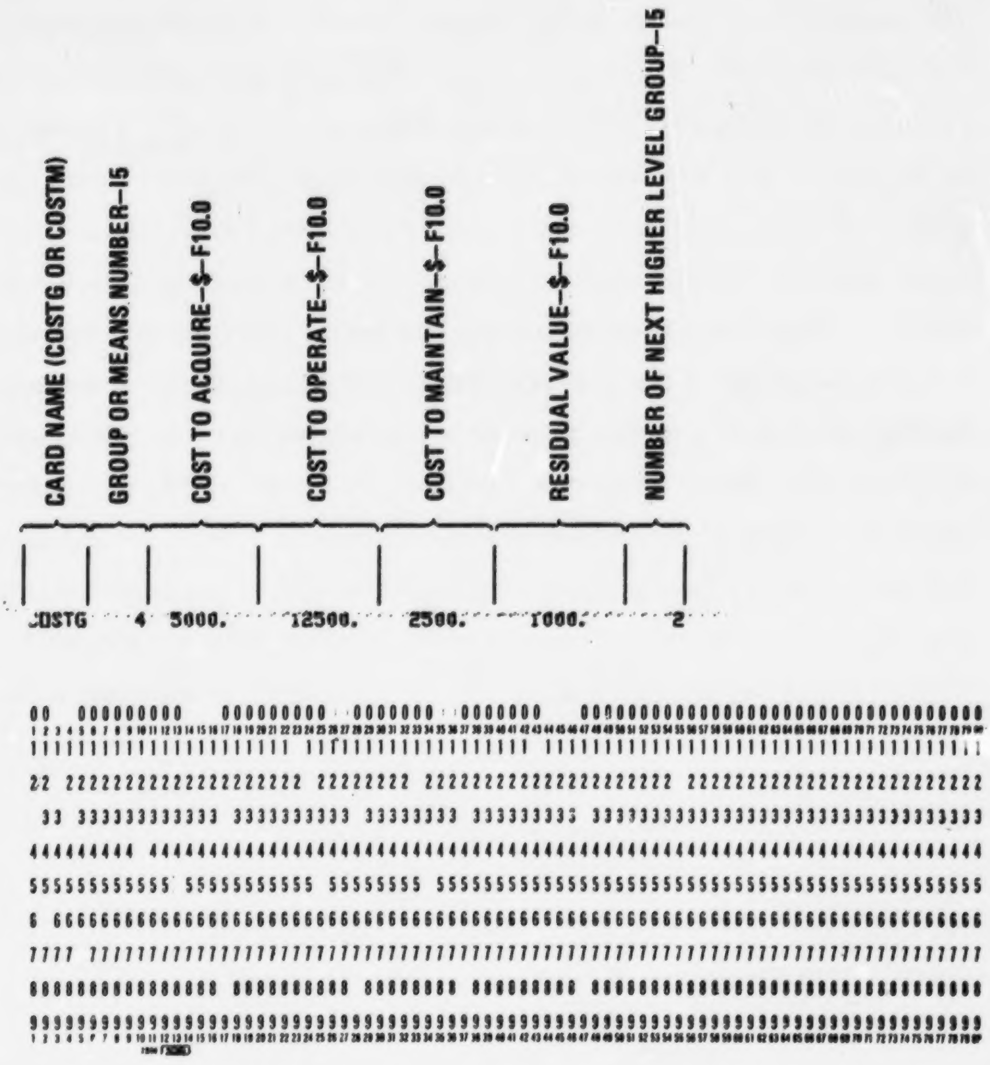

CARD NAME (COSTG OR COSTM)
GROUP OR MEANS NUMBER—I5
COST TO ACQUIRE—$—F10.0
COST TO OPERATE—$—F10.0
COST TO MAINTAIN—$—F10.0
RESIDUAL VALUE—$—F10.0
NUMBER OF NEXT HIGHER LEVEL GROUP—I5
COSTG
4
5000.
12500.
2500.
1000.
2

Figure 45. COST Card Format

Adaptation to Computer Facility

The computer programs for design analysis have been prepared and tested on a CDC 6700 computer. Some care has been taken to maintain generality in the program, but that has not always been feasible. As discussed in Appendix E, use is made of the 60-bit word length available on the CDC 6700. Minor program modifications are necessary to adapt the programs to a smaller word-length machine. Another adaptation required is in the handling of the USGS flow data tape. A special purpose subroutine (Subroutine GSTAPE) must be prepared to handle the gaging station data tape with the hardware available at the user facility. Appendix F provides guidance in the preparation of the subroutine. As usual in a new program application, attention must be paid to all the input/output specifications when implementing on a new computer. Finally, for any given application, some adjustments of the storage allocated to data arrays may be necessary. The array sizes specified in the program listings (Appendix F) are relatively arbitrary and based on the requirements of the demonstration case.

SECTION VIII

DEMONSTRATION OF DESIGN METHODS

In order to illustrate the major features of the surveillance system design methods, the methods are demonstrated for the Beaver River Basin of Ohio and Pennsylvania. Various alternative systems are analyzed to highlight relationships among the several factors incorporated in the analysis.

The section begins with introductory remarks concerning the significance the demonstration results and the choice of the Beaver River Basin as the demonstration basin. A brief description of the Basin follows. Then, the primary demonstration case is described on a task-by-task level. The results of the primary demonstration are discussed and used as a point of departure for various permutations of the primary case. The section is concluded with a summary of the demonstration.

CAVEAT

The objective of the demonstration is to illustrate features of the design method. The selection and use of the Beaver River Basin to achieve this objective is based on the practical considerations discussed below and does not constitute a statement of opinion concerning the water quality of the Basin. The results of the demonstration are based on a careful application of the design method to the data used. In many cases that data is intentionally artificial, in order to avoid appearing to recommend a particular surveillance method or device. Specifically, the cost data and the reliability data are to be considered artificial, although the range of values has been guided by [4, 10, and 28]. Therefore, the results of the demonstration do not constitute a fully realistic recommendation for water quality surveillance in the Beaver River Basin and must be viewed in the light of these limitations.

SELECTION OF BEAVER RIVER BASIN

Choice of the Beaver River Basin for use as the demonstration case was based almost entirely on a pragmatic consideration: three calibrated Standard Data Decks already existed for the basin [7]. Thus, in a project directed primarily at development of design methods, the effort expended in preparing for demonstration of those methods could be minimized.

In addition, the Beaver River Basin can be considered qualitatively typical of many river basins in the country. It has a broad range of uses, including public water supply, industrial water supply, municipal sanitation and runoff removal, recreation and wildlife support. It includes both major dams for reservoirs and minor, run-of-the-stream dams for industrial supply. Problems in the basin include mine drainage, municipal waste treatment and industrial discharges, primarily from the steel industry.

Another factor influencing the choice is the political division of the Basin between two states, Ohio and Pennsylvania. This factor permits the demonstration of features of the method for dealing with changes in authority.

Description of Beaver River Basin

The geographical location and extent of the Beaver River Basin is mapped in Figure 46. The basin is drained primarily by the Mahoning and Shenango Rivers, which join in western Pennsylvania to form the Beaver River. The Beaver is ultimately tributary to the Ohio River. The northern half of the basin is relatively flat, while the southern half includes western parts of the Allegheny Mountains. Particularly in its lower reaches, the Beaver River lies in a narrow, rugged valley cut through a plateau [29]. Included in the basin is the highly industrialized area in the vicinity of Youngstown, Ohio.

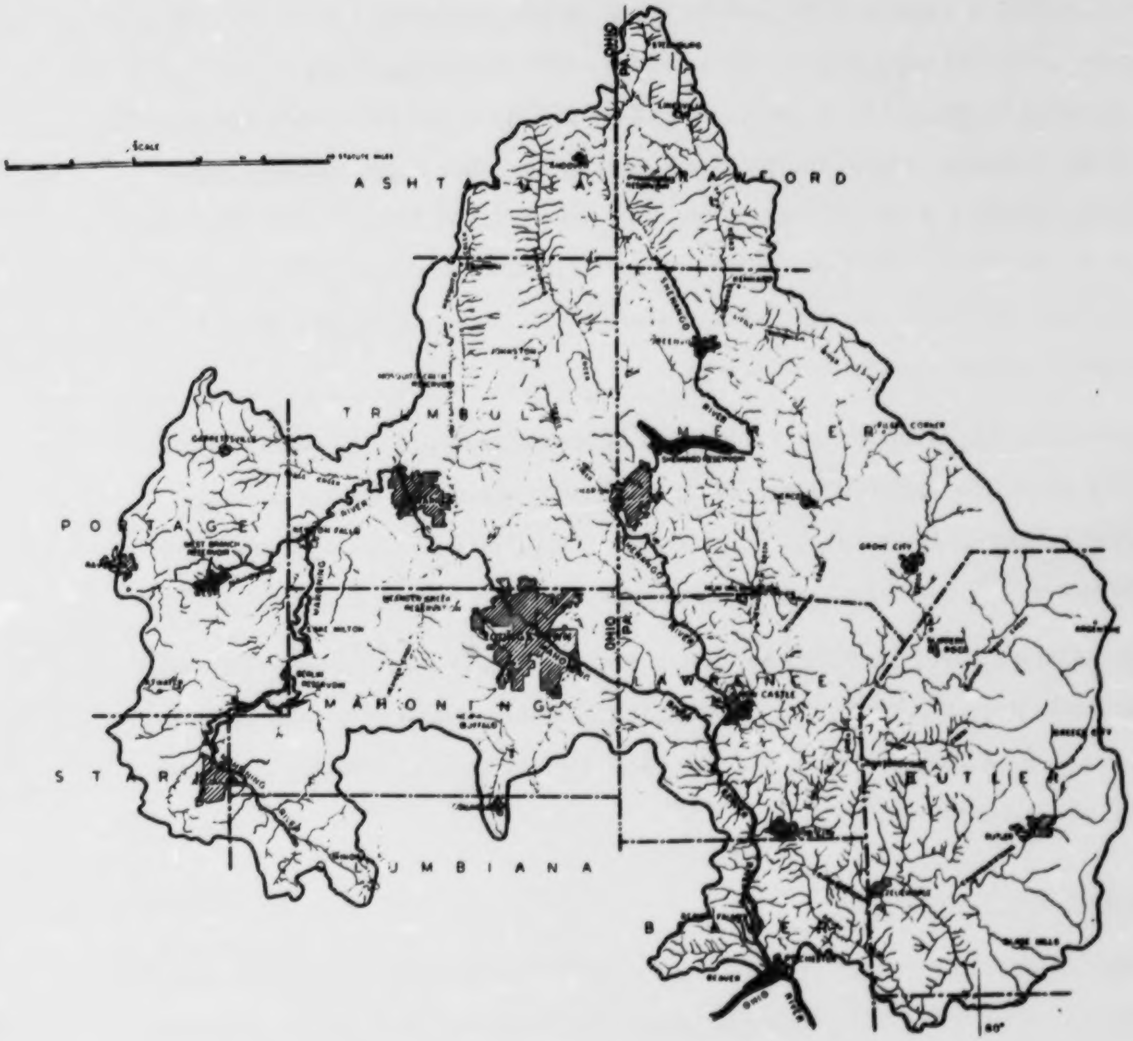

SCALE
ASHTABULA
CRAWFORD
TRUMBULL
MERCER
PORTAGE
MAHONING
LAWRENCE
BUTLER
STARK
COLUMBIANA
BEAVER
OHIO
NEW CASTLE
GROVE CITY
OHIO RIVER

Figure 46. Beaver River Basin

The Mahoning River drains an area of approximately 1,130 square miles, most of which is in eastern Ohio, and its length is approximately 110 miles. Its principal tributaries are the West Branch of the Mahoning, Eagle Creek, Mosquito Creek and Meander Creek. Five multipurpose reservoirs are located in the Mahoning sub-basin, for flood control, low-flow augmentation, public water supply and recreation. In addition, between Levittsburg and Lowellville on the Mahoning, there is a series of low dams that pond water for industrial intakes. Earthfills for railroads and mills also constrict the flow along the natural stream channel in this area.

The Shenango River drains a total area of approximately 1,080 square miles, with about 285 square miles in Ohio and the remaining 795 square miles in Pennsylvania. Its length to the confluence with the Mahoning is approximately 52 miles. Two multipurpose reservoirs are located on the upper Shenango.

The Beaver River, from its head near New Castle, Pennsylvania, to its mouth at Rochester, Pennsylvania, is about 21.4 miles in length. Its total drainage area, including the areas drained by the Mahoning and the Shenango, is about 3,145 square miles [30].

Water Quality Problems

The major water quality problems in the Beaver River Basin are due to discharge of domestic and industrial waste. Agriculture, dairying and food processing are also of some importance.

Several large industrial centers are located within the basin, contributing massive manufacturing waste discharges to the rivers. The greatest industrial concentration is in and around Youngstown, Ohio, the largest city in the Basin. Other areas of intense industrial activity, principally iron and steel industry, are found at Warren, Niles, Girard and McDonald on the Mahoning River, and at Sharpsville, Sharon, Farrel and New Castle on the Shenango. Industrial activity along the Beaver River is present at Koppel, West Mayfield, Beaver Falls and Fallston.

In addition to the dominant iron and steel industry, basin industrial activity includes chemicals, lumber, glass, textiles, quarrying of high quality limestone, and the manufacturing of cement.

Population concentrations in the basin correspond to industrial centers. The total population of the Beaver River Basin today is in excess of 800,000 people [29], but domestic waste from more than half of this population is discharged along the 25 mile stretch of the Mahoning from Warren to Lowellville. Prior to 1960 nearly 50% of that effluent was left untreated, particularly in the Youngstown area [29]. Since then, measures have been taken to bring at least primary treatment to all sewered populations in the portion of the basin considered. As of 1960, as many as 59 communities discharged significant amounts of treated and untreated municipal wastes to the streams of the basin [29].

Effects of Pollution

The effects of poor water quality in the Beaver River Basin can be seen in both the natural biological sphere and the human economic sphere.

Aquatic life in the rivers of the basin has been drastically influenced by poor water quality. The Mahoning River in the vicinity of Younstown, Ohio, may serve as an example. Downstream of Youngstown to the state boundary, the river is completely devoid of bottom fauna, in contrast to the diverse and abundant benthic life found in its headwaters [31].

Reproduced from best available copy.

The economic effect can be illustrated by the impact of water quality on the public water supply at Beaver Falls, Pennsylvania. The Mahoning River, degraded by the considerable impact of Youngstown, Ohio, is an important contributor of pollution to the Beaver River. Consequently, the use of the Beaver River for public water supply is affected by excessively high bacteriological counts, by high variability in hardness, iron and other physical/chemical properties, and by tastes and odors resulting from domestic and industrial wastes. Thus, Beaver Falls must absorb the expense of the very difficult and extensive water supply treatment required [29].

The Basin Subset

The portion of the Beaver River Basin included in the surveillance system design/model, the so-called "basin subset", is of limited geographical extent. The stretches of river to be included are (Figure 47):

1. The Mahoning River from Alliance, Ohio, to the confluence with the Shenango River
2. The Mosquito Creek from the Mosquito Creek Dam to the confluence with the Mahoning River.
3. The Shenango River from Sharpsville, Pennsylvania, to the confluence with the Mahoning River
4. The Beaver River from the confluence of the Mahoning and Shenango Rivers to its mouth at the Ohio River.

This "basin subset" includes two of the multipurpose reservoirs discussed above, the Berlin and the Milton reservoirs. A list of the major tributaries to the basin subset, with their respective drainage areas, is found in Table 8.

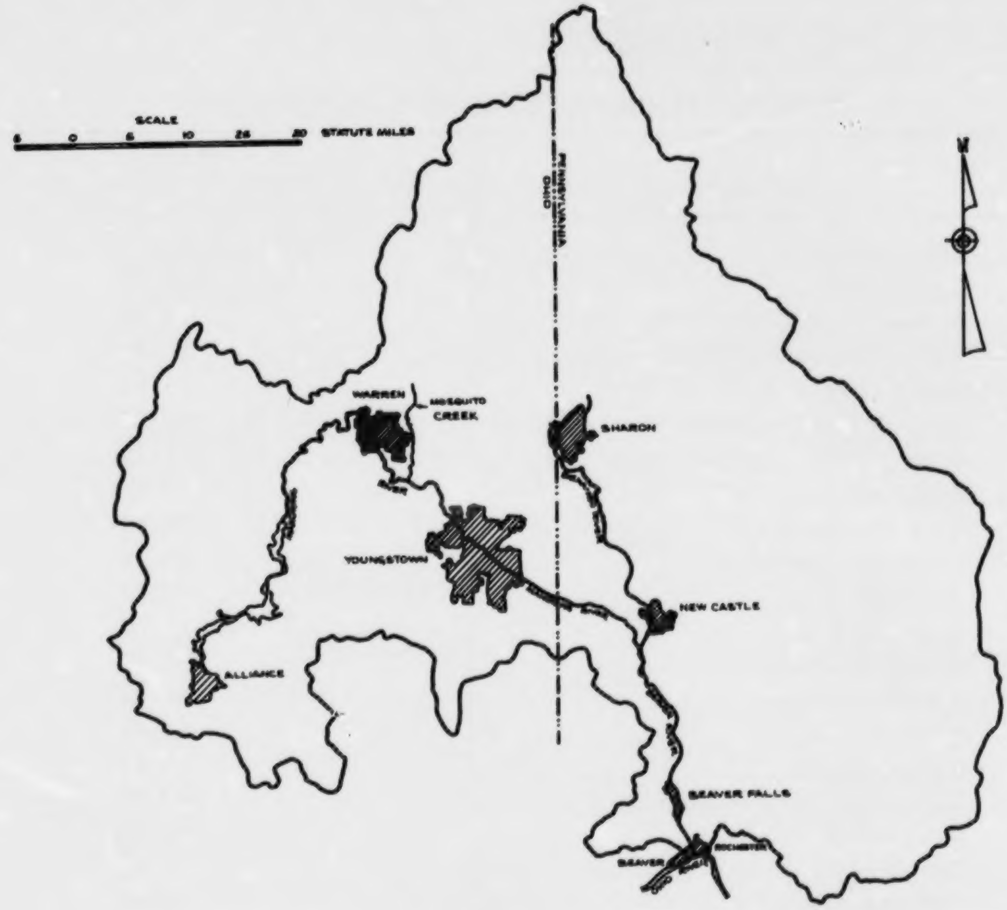

SCALE
5 0 5 10 15 20 STATUTE MILES
N
PENNSYLVANIA
OHIO
WARREN
MOSQUITO CREEK
SHARON
YOUNGSTOWN
NEW CASTLE
ALLIANCE
BEAVER FALLS
ROCHESTER
BEAVER

Figure 47. Stretches of River Included in Basin Street

Table 8. MAJOR TRIBUTARIES TO BASIN SUBSET

Tributary	Draining Area (sq. mi.)
Beech Creek	33.42
Deer Creek	35.71
Willow Creek	19.90
Mill Creek (to Berlin Reservoir)	31.76
Kale Creek	24.24
West Branch Mahoning River	109.36
Eagle Creek	109.53
Chocolate Run	4.50
Duck Creek	36.71
Infirmary Run	10.51
Red Run	7.20
Mud Creek	11.23
Mosquito Creek	139.33
Meander Creek	83.56
Squaw Creek	17.32
Fourmile Run	4.69
Mill Creek (near Youngstown)	79.10
Crab Creek	20.28
Dry Run	10.11
Yellow Creek	32.43
Coffee Run	10.26
Hickory Run	24.24
Neshannock Creek	244.00
Big Run	33.90
Connoquenessing Creek	829.00

PRIMARY DEMONSTRATION CASE

Application of the design method to the Beaver River Basin calls for the performance of the six tasks detailed in Section VII. The actions and results of each task are described in the following paragraphs for a case in which a totally manual system of surveillance is compared with a totally automatic system. When constraints have been applied solely for purposes of the demonstration, they are clearly labeled.

Task 1 - Data Assembly

Because the demonstration draws on the results of the Beaver River Basin Modeling Project, most of the data acquisition process may be considered to have been completed. The reader is referred to [7] and [18] for a complete discussion of the data on the Beaver River Basin. The major action of Task 1 is, thus, the very important choice of the water quality parameters to be included in the design analysis.

Four water quality parameters are considered for incorporation in the monitoring system:

1. Dissolved Oxygen
2. Cyanides (Ohio portion of Basin)
3. Phenols (Pennsylvania portion of Basin)
4. Dissolved Solids.

The criteria for selection are a combination of the general requirements for inclusion in design analysis and of the specific requirements of the demonstration.

The general requirements reflect the water quality standards in force in the Basin. The Ohio standards for the Mahoning River include absolute limits on dissolved oxygen, cyanides and dissolved solids, along with a number of other parameters. Ohio standards for phenols in the Mahoning River are referenced to ambient. Similarly, the Pennsylvania standards for the Mahoning, Shenango and Beaver Rivers include absolute limits for dissolved oxygen, phenols and dissolved solids. In Pennsylvania, cyanides fall under the more general provision calling for freedom from toxic substances in the Beaver Basin. Thus, these four water quality parameters would ordinarily be among those selected for inclusion in a monitoring network.

The specific requirements for demonstration call for one parameter from each of the three classes of water quality parameters:

1. Conservative
2. Non-conservative, non-coupled
3. Non-conservative, coupled.

For reasons of economy, use of only one parameter from each class is preferred for the demonstration. The requirements of the demonstration also call for selection of parameters for which both manual and automatic surveillance methods are available, so comparisons can be made between the two types of approaches.

Thus, the four parameters have been selected for demonstration, because they satisfy the requirements of the demonstration. Dissolved oxygen is modeled as a non-conservative, coupled parameter, with established thresholds throughout the Basin. Cyanides is modeled as a non-conservative, non-coupled parameter, with established thresholds in the Ohio portion of the Basin and an implied zero threshold in the Pennsylvania portion. Phenols is modeled as a non-conservative, non-coupled parameter, with established, absolute thresholds in the Pennsylvania portion of the Basin. For the Ohio portion of the Basin, an artificial, high threshold for phenols is arbitrarily used in lieu of an established state standard. Dissolved solids is modeled as a conservative parameter, with established thresholds throughout the Basin.

The threshold concentrations used in the demonstration are listed in Table 9 by region of application.

Task 2 - Basin Modeling

Once again, the activities associated with Task 2 can be considered to have been completed within the Beaver River Basin Modeling Project. During that project, three calibrated Standard Data Decks were prepared:

1. September 1970
2. March 1971
3. August 1971.

For purposes of the present demonstration, the September 1970 baseline period is used as the design condition. It is selected for two reasons: 1) it corresponds

Table 9. THRESHOLD CONCENTRATIONS ASSUMED FOR PURPOSES OF DEMONSTRATION (mg/l)

Parameter	Parameter Number	Ohio	Pennsylvania
Dissolved Solids	5	1500.0	500.0
Cyanides	10	0.005	0.000
Phenols	11	0.100	0.005
Dissolved Oxygen	17	5.000	5.000

to low-flow conditions near the end of the water year and 2) the other low-flow period (August 1971) includes data taken during a major shutdown of the steel mills in the Basin.

A complete description of the calibration of RIBAM for the Beaver River Basin can be found in [7].

In summary, the Basin is segmented into 38 reaches, as shown in Figures 48, 49 and 50. The head of each reach corresponds to a major point-source, impact

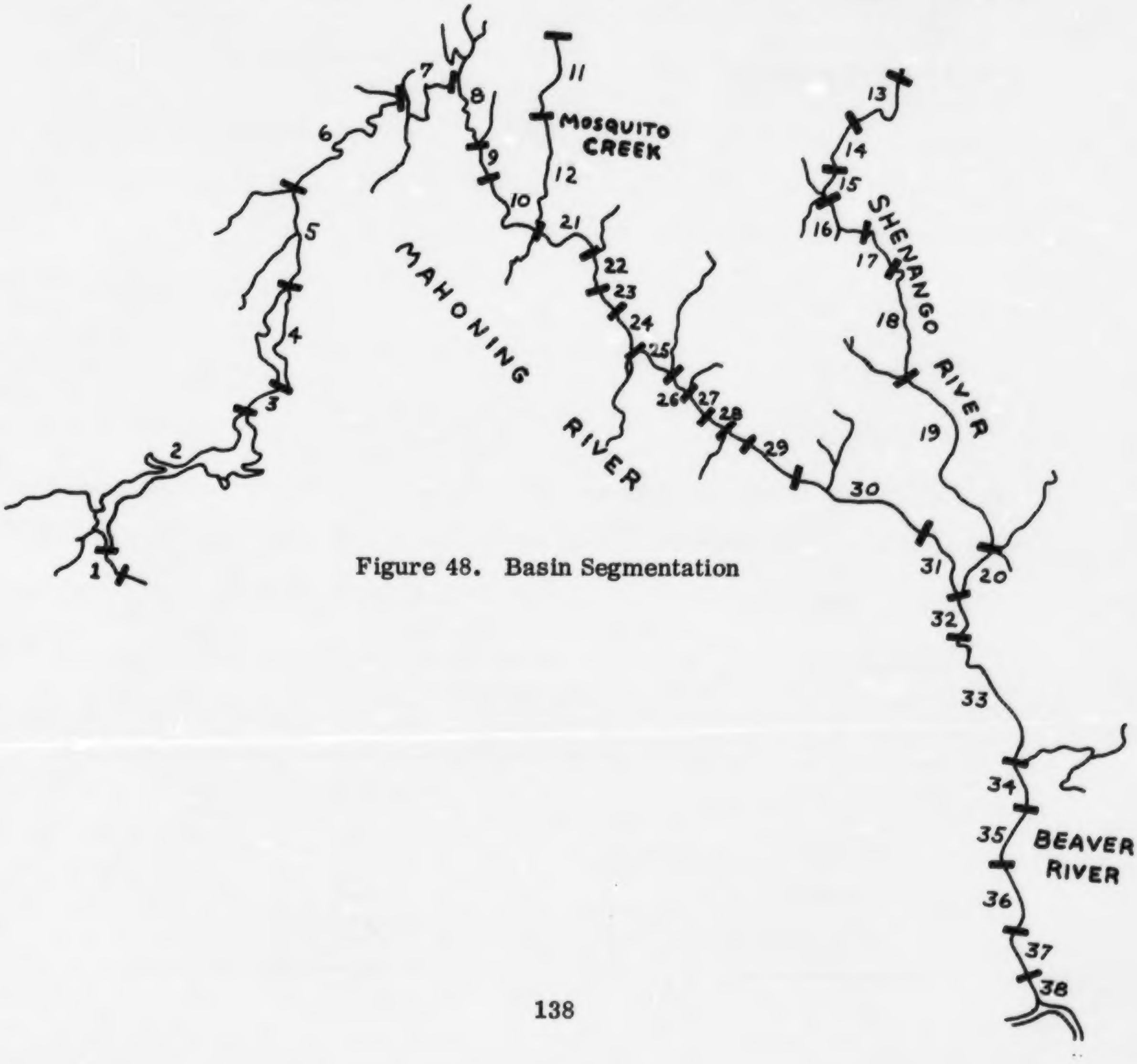

MOSQUITO CREEK
MAHONING RIVER
SHENANGO RIVER
BEAVER RIVER
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38

Figure 48. Basin Segmentation

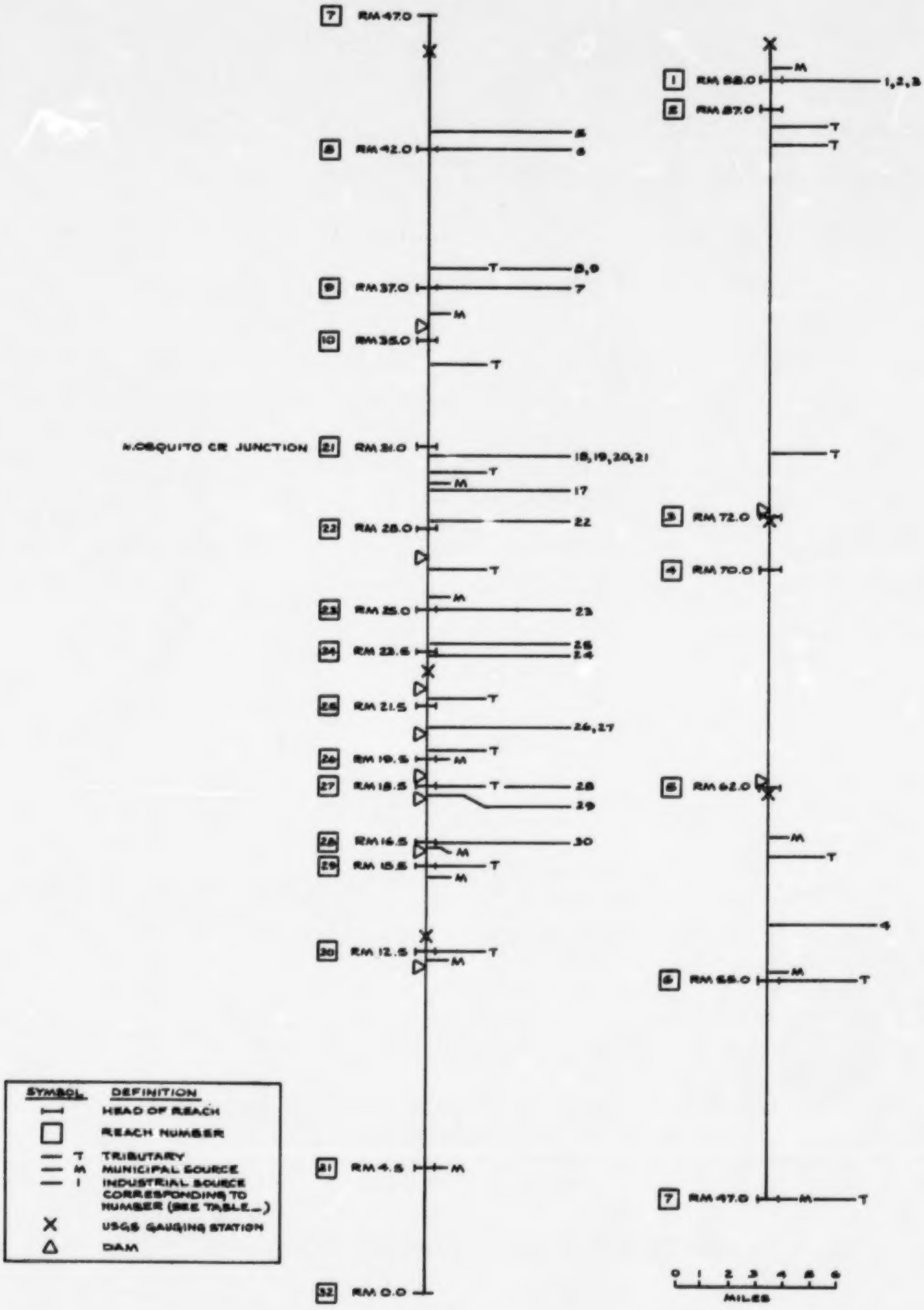

7 RM 47.0
8 RM 42.0
5
6
T
8,9
9 RM 37.0
7
M
10 RM 35.0
T
MOSQUITO CR JUNCTION
21 RM 31.0
18,19,20,21
T
M
17
22 RM 28.0
22
T
M
23 RM 25.0
23
24 RM 22.6
25
24
25 RM 21.5
T
26,27
26 RM 19.5
T
M
27 RM 18.5
T
28
29
28 RM 16.5
30
M
29 RM 15.5
T
M
30 RM 12.5
T
M
31 RM 4.5
M
32 RM 0.0
M
1 RM 88.0
1,2,3
2 RM 87.0
T
T
T
3 RM 72.0
4 RM 70.0
5 RM 62.0
M
T
4
6 RM 55.0
M
T
7 RM 47.0
M
T
0 1 2 3 4 5 6
MILES
SYMBOL
DEFINITION
HEAD OF REACH
REACH NUMBER
T TRIBUTARY
M MUNICIPAL SOURCE
I INDUSTRIAL SOURCE CORRESPONDING TO NUMBER (SEE TABLE _)
X USGS GAUGING STATION
Δ DAM

Figure 49. Basin Stick Diagram (Mahoning River Section)

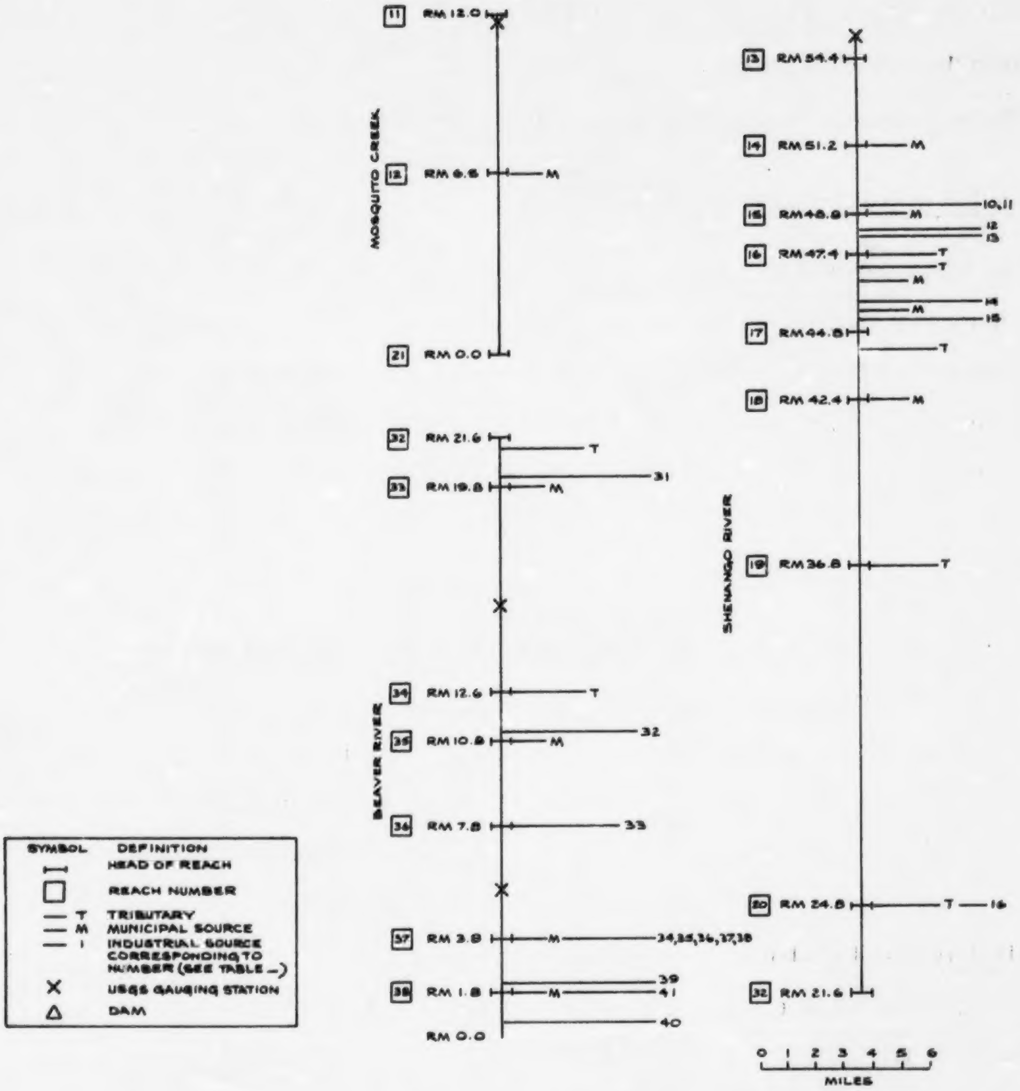

MOSQUITO CREEK
11 RM 12.0
12 RM 6.6
M
21 RM 0.0
32 RM 21.6
T
33 RM 19.8
M
31
BEAVER RIVER
34 RM 12.6
T
35 RM 10.8
M
32
36 RM 7.8
33
37 RM 3.8
M
34,35,36,37,38
38 RM 1.8
39
M
41
RM 0.0
40
SHENANGO RIVER
13 RM 54.4
14 RM 51.2
M
15 RM 48.8
M
10,11
12
13
16 RM 47.4
T
T
M
14
M
15
17 RM 44.8
T
18 RM 42.4
M
19 RM 36.8
T
20 RM 24.8
T
16
32 RM 21.6
0 1 2 3 4 5 6
MILES
SYMBOL
DEFINITION
HEAD OF REACH
REACH NUMBER
T TRIBUTARY
M MUNICIPAL SOURCE
I INDUSTRIAL SOURCE CORRESPONDING TO NUMBER (SEE TABLE _)
USGS GAUGING STATION
DAM

Figure 50. Basin Stick Diagram (Shenango-Beaver Section)

nucleus (group of sources), tributary junction or change of physical characteristics, as diagrammed. The USGS gaging stations used to develop stream flow data are shown in Figure 51. Of the 16 stations shown, only the eight indicated have data records sufficient to the design method. Thus, only those eight stations are used in the preliminary and final design runs.

Task 3 - Preliminary Design

The major results of Task 3 are contained in the computer print-outs shown in Figures 52, 53, 54, and 55. They are the product of the design analysis programs described in Section VII, used in the preliminary design mode. The September 1970 Standard Data Deck and 60 months of USGS flow data beginning with January 1957 constitute the major input data, along with the threshold concentrations from Table 9. A complete listing of the input data deck may be found in Appendix G.

As indicated in Figure 52, violations of the dissolved solids standards begin in only one segment, reach 30. The value in the column labelled "EXP. NO. OF VIOLATIONS" indicates that slightly less than 3 violations of dissolved solids may be expected each year in reach 30. The values for the other reaches are a nominally low value, indicating that no violations were found over the 5 year (1826 day) flow record searched. The violations in reach 30 are associated directly with the change in dissolved solids threshold from 1500 mg/l on the Ohio side of the line (reach 29) to 500 mg/l on the Pennsylvania side (reach 30). As indicated, these violations may be expected to last about 6 days, with about 124 days between violations. The preferred sampling location is, of course, irrelevant for a conservative parameter such as dissolved solids.

Turning to cyanides (Figure 53), it can be seen that a number of reaches may be expected to be continuously in violation, while only one reach (reach 21) has any

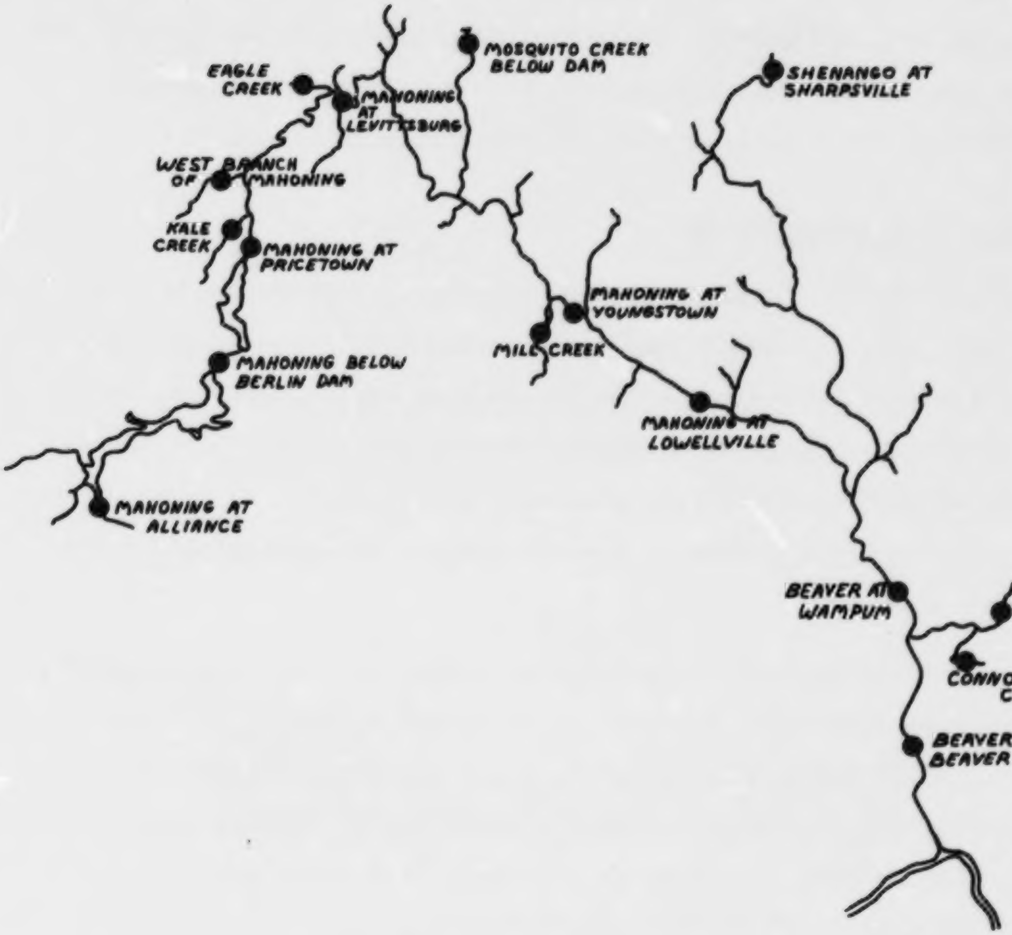

EAGLE CREEK
MAHONING AT LEVITTSBURG
MOSQUITO CREEK BELOW DAM
SHENANGO AT SHARPSVILLE
WEST BRANCH OF MAHONING
KALE CREEK
MAHONING AT PRICETOWN
MAHONING AT YOUNGSTOWN
MILL CREEK
MAHONING BELOW BERLIN DAM
MAHONING AT LOWELLVILLE
MAHONING AT ALLIANCE
BEAVER AT WAMPUM
SLIPPERY ROCK CREEK
CONNOQUENESSING CREEK
BEAVER AT BEAVER FALLS

Figure 51. USGS Gaging Stations in the Beaver River Basin

```
PARAMETER =  5

REACH NO.    EXP. NO. OF     EXP. DURATION OF     EXP. DURATION OF     PREF. SAMPLING
             VIOLATIONS      A VIOLATION          A NON-VIOLATION      LOCATION,R.M.

     1       1.99890E-01     0.                        1.82600E+03          88.0
     2       1.99890E-01     0.                        1.82600E+03          87.0
     3       1.99890E-01     0.                        1.82600E+03          72.0
     4       1.99890E-01     0.                        1.82600E+03          70.0
     5       1.99890E-01     0.                        1.82600E+03          62.0
     6       1.99890E-01     0.                        1.82600E+03          55.0
     7       1.99890E-01     0.                        1.82600E+03          47.0
     8       1.99890E-01     0.                        1.82600E+03          42.0
     9       1.99890E-01     0.                        1.82600E+03          37.0
    10       1.99890E-01     0.                        1.82600E+03          35.0
    11       1.99890E-01     0.                        1.82600E+03          12.0
    12       1.99890E-01     0.                        1.82600E+03           6.5
    13       1.99890E-01     0.                        1.82600E+03          54.4
    14       1.99890E-01     0.                        1.82600E+03          51.2
    15       1.99890E-01     0.                        1.82600E+03          48.8
    16       1.99890E-01     0.                        1.82600E+03          47.4
    17       1.99890E-01     0.                        1.82600E+03          44.8
    18       1.99890E-01     0.                        1.82600E+03          42.4
    19       1.99890E-01     0.                        1.82600E+03          36.8
    20       1.99890E-01     0.                        1.82600E+03          24.8
    21       1.99890E-01     0.                        1.82600E+03          31.0
    22       1.99890E-01     0.                        1.82600E+03          28.0
    23       1.99890E-01     0.                        1.82600E+03          25.0
    24       1.99890E-01     0.                        1.82600E+03          23.5
    25       1.99890E-01     0.                        1.82600E+03          21.5
    26       1.99890E-01     0.                        1.82600E+03          19.5
    27       1.99890E-01     0.                        1.82600E+03          18.5
    28       1.99890E-01     0.                        1.82600E+03          16.5
    29       1.99890E-01     0.                        1.82600E+03          15.5
    30       2.79847E+00     6.21429E+00               1.24214E+02          12.5
    31       1.99890E-01     0.                        1.82600E+03           4.5
    32       1.99890E-01     0.                        1.82600E+03          21.6
    33       1.99890E-01     0.                        1.82600E+03          19.8
    34       1.99890E-01     0.                        1.82600E+03          12.6
    35       1.99890E-01     0.                        1.82600E+03          10.8
    36       1.99890E-01     0.                        1.82600E+03           7.8
    37       1.99890E-01     0.                        1.82600E+03           3.8
    38       1.99890E-01     0.                        1.82600E+03           1.8
```

Figure 52. Preliminary Design Data for Dissolved Solids

```
PARAMETER = 10

REACH NO.    EXP. NO. OF     EXP. DURATION OF     EXP. DURATION OF     PREF. SAMPLING
             VIOLATIONS      A VIOLATION          A NON-VIOLATION      LOCATION,R.M.

     1       1.99890E-01     0.                        1.82600E+03          88.0
     2       1.99890E-01     0.                        1.82600E+03          87.0
     3       1.99890E-01     0.                        1.82600E+03          72.0
     4       1.99890E-01     0.                        1.82600E+03          70.0
     5       1.99890E-01     0.                        1.82600E+03          62.0
     6       1.99890E-01     0.                        1.82600E+03          55.0
     7       1.99890E-01     0.                        1.82600E+03          47.0
     8       1.99890E-01     0.                        1.82600E+03          42.0
     9       1.99890E-01     1.82600E+03               0.                   37.0
    10       1.99890E-01     0.                        1.82600E+03          35.0
    11       1.99890E-01     0.                        1.82600E+03          12.0
    12       1.99890E-01     0.                        1.82600E+03           6.5
    13       1.99890E-01     0.                        1.82600E+03          54.4
    14       1.99890E-01     0.                        1.82600E+03          51.2
    15       1.99890E-01     1.82600E+03               0.                   48.8
    16       1.99890E-01     0.                        1.82600E+03          47.4
    17       1.99890E-01     0.                        1.82600E+03          44.8
    18       1.99890E-01     0.                        1.82600E+03          42.4
    19       1.99890E-01     0.                        1.82600E+03          36.8
    20       1.99890E-01     0.                        1.82600E+03          24.8
    21       2.37356E+01     3.94915E+00               1.14286E+01          31.0
    22       1.99890E-01     0.                        1.82600E+03          28.0
    23       1.99890E-01     0.                        1.82600E+03          25.0
    24       1.99890E-01     1.82600E+03               0.                   23.5
    25       1.99890E-01     0.                        1.82600E+03          21.5
    26       1.99890E-01     0.                        1.82600E+03          19.5
    27       1.99890E-01     0.                        1.82600E+03          18.5
    28       1.99890E-01     1.82600E+03               0.                   16.5
    29       1.99890E-01     0.                        1.82600E+03          15.5
    30       1.99890E-01     0.                        1.82600E+03          12.5
    31       1.99890E-01     0.                        1.82600E+03           4.5
    32       1.99890E-01     0.                        1.82600E+03          21.6
    33       1.99890E-01     0.                        1.82600E+03          19.8
    34       1.99890E-01     0.                        1.82600E+03          12.6
    35       1.99890E-01     0.                        1.82600E+03          10.8
    36       1.99890E-01     0.                        1.82600E+03           7.8
    37       1.99890E-01     0.                        1.82600E+03           3.8
    38       1.99890E-01     0.                        1.82600E+03           1.8
```

Figure 53. Preliminary Design Data for Cyanides

```
PARAMETER = 11

REACH NO.     EXP. NO. OF     EXP. DURATION OF     EXP. DURATION OF     PREF. SAMPLING
              VIOLATIONS      A VIOLATION          A NON-VIOLATION      LOCATION.R.M.


    1          1.99890E-01     0.                      1.82600E+03           88.0
    2          1.99890E-01     0.                      1.82600E+03           87.0
    3          1.99890E-01     0.                      1.82600E+03           72.0
    4          1.99890E-01     0.                      1.82600E+03           70.0
    5          1.99890E-01     0.                      1.82600E+03           62.0
    6          1.99890E-01     0.                      1.82600E+03           55.0
    7          1.99890E-01     0.                      1.82600E+03           47.0
    8          1.99890E-01     0.                      1.82600E+03           42.0
    9          1.32896E+01     1.32985E+01             1.41667E+01           37.0
   10          1.99890E-01     0.                      1.82600E+03           35.0
   11          1.99890E-01     0.                      1.82600E+03           12.0
   12          1.99890E-01     0.                      1.82600E+03            6.5
   13          1.99890E-01     0.                      1.82600E+03           54.4
   14          1.99890E-01     0.                      1.82600E+03           51.2
   15          1.99890E-01     0.                      1.82600E+03           48.8
   16          1.99890E-01     0.                      1.82600E+03           47.4
   17          1.99890E-01     0.                      1.82600E+03           44.8
   18          1.99890E-01     0.                      1.82600E+03           42.4
   19          1.99890E-01     0.                      1.82600E+03           36.8
   20          1.99890E-01     0.                      1.82600E+03           24.8
   21          3.79376E+00     2.00000E+00             9.42105E+01           31.0
   22          1.99890E-01     0.                      1.82600E+03           28.0
   23          1.99890E-01     0.                      1.82600E+03           25.0
   24          1.55915E+01     4.35897E+00             1.90513E+01           23.5
   25          1.99890E-01     0.                      1.82600E+03           21.5
   26          1.99890E-01     0.                      1.82600E+03           19.5
   27          1.59787E+00     1.42857E+00             2.27000E+02           18.5
   28          1.67908E+01     1.29643E+01             8.77381E+00           16.5
   29          2.05675E+01     1.88235E+00             1.58641E+01           15.5
   30          1.27404E+01     7.53968E+00             2.11094E+01           12.5
   31          1.99890E-01     0.                      1.82600E+03            4.5
   32          1.99890E-01     0.                      1.82600E+03           21.6
   33          1.99890E-01     0.                      1.82600E+03           19.8
   34          1.99890E-01     0.                      1.82600E+03           12.6
   35          1.99890E-01     0.                      1.82600E+03           10.8
   36          1.99890E-01     0.                      1.82600E+03            7.8
   37          1.99890E-01     0.                      1.82600E+03            3.8
   38          1.99890E-01     0.                      1.82600E+03            1.8
```

Figure 54. Preliminary Design Data for Phenols

```
PARAMETER = 17

REACH NO.     EXP. NO. OF     EXP. DURATION OF     EXP. DURATION OF     PREF. SAMPLING
              VIOLATIONS      A VIOLATION          A NON-VIOLATION      LOCATION.R.M.


    1          1.99890E-01     0.                      1.82600E+03           87.0
    2          3.38044E+00     9.84118E+01             9.56250E+00           82.5
    3          1.99890E-01     0.                      1.82600E+03           70.0
    4          1.99890E-01     0.                      1.82600E+03           65.2
    5          1.99890E-01     0.                      1.82600E+03           57.1
    6          1.99890E-01     0.                      1.82600E+03           53.4
    7          1.99890E-01     0.                      1.82600E+03           43.0
    8          1.99890E-01     0.                      1.82600E+03           39.5
    9          1.99890E-01     0.                      1.82600E+03           35.0
   10          7.91614E-01     1.83333E+01             4.42750E+02           31.0
   11          1.99890E-01     0.                      1.82600E+03           11.4
   12          1.99890E-01     0.                      1.82600E+03            3.3
   13          1.99890E-01     0.                      1.82600E+03           51.2
   14          1.99890E-01     0.                      1.82600E+03           48.8
   15          1.99890E-01     0.                      1.82600E+03           47.4
   16          7.94198E-01     1.23333E+01             4.47250E+02           44.8
   17          7.55992E+00     8.67568E+00             3.96053E+01           42.4
   18          1.70620E+01     7.62791E+00             1.37647E+01           36.8
   19          9.98905E-01     1.00000E+00             3.64400E+02           35.6
   20          1.99890E-01     0.                      1.82600E+03           24.5
   21          1.99890E-01     1.82600E+03             0.                    28.0
   22          1.99890E-01     0.                      1.82600E+03           25.0
   23          1.99890E-01     0.                      1.82600E+03           23.5
   24          1.99890E-01     0.                      1.82600E+03           21.5
   25          1.99890E-01     0.                      1.82600E+03           19.5
   26          1.99890E-01     0.                      1.82600E+03           18.5
   27          1.99890E-01     0.                      1.82600E+03           16.5
   28          1.99890E-01     0.                      1.82600E+03           15.5
   29          1.99890E-01     0.                      1.82600E+03           12.5
   30          1.99890E-01     0.                      1.82600E+03            4.5
   31          1.99890E-01     0.                      1.82600E+03            4.0
   32          1.99890E-01     0.                      1.82600E+03           21.4
   33          1.99890E-01     0.                      1.82600E+03           19.1
   34          1.99890E-01     0.                      1.82600E+03           12.4
   35          1.91895E+01     5.15625E+00             1.38646E+01            7.8
   36          1.29839E+01     1.26563E+00             2.68462E+01            4.6
   37          1.99890E-01     0.                      1.82600E+03            3.6
   38          1.99890E-01     0.                      1.82600E+03            1.6
```

Figure 55. Preliminary Design Data for Dissolved Oxygen

variability. The reaches continuously in violation have the same low likelihood of a new violation as those continuously free of violation. In reach 21, we expect about 24 new violations per year, each of about 4 days duration, with about 11 days between. The preferred sampling location, 31.0 river miles above the confluence with the Shenango, corresponds to the head of reach 21, since cyanides are modeled as a non-conservative, non-coupled parameter.

The preliminary design data for phenols (Figure 54) indicate a greater variability than for the previous two parameters. A number of new violations can be expected to begin in reaches 9, 21, 24, 27, 28, 29, and 30. Of these, only reach 30 is in Pennsylvania, where a threshold for phenols is established. The violations in reaches 9, 21, 24, 27, 28, and 29 are violations of a concentration threshold set 20 times higher than the Pennsylvania standard, to simulate the assumed lack of a phenols standard in Ohio.

Finally, the dissolved oxygen standard may be expected to be violated in reaches 2, 10, 16, 17, 18, 19, 21, 35, and 36 (Figure 55). Of those, reach 21 is continuously in violation. The preferred sampling locations correspond to the oxygen sag point or the lower end of the reach, whichever is further upstream. For example, the preferred sampling location in reach 35 is 7.8 river miles, corresponding to the head of reach 36. This indicates that the sag point for the source at the head of reach 35 lies somewhere in or downstream of reach 36.

Task 4 - Candidate Design

Using the data in Figures 52, 53, 54 and 55, two candidate systems are designed for comparison using the final design mode of the analysis programs. The two candidates are intended to monitor the same reaches of the Basin. Beyond that, they have been designed to make normal use of the means to be incorporated.

Candidate 1.0 is a totally manual monitoring system, while Candidate 2.0 is a fully automatic system.

Candidate 1.0 —

The initial decision in the design of the totally manual system concerns the selection of the nominal system characteristics: parameters monitored, segments monitored, and system duration (Table 4). For purposes of the demonstration, the system duration is initially chosen to be 1 year. Since the preliminary design data indicate violations of each of the parameters, the system will monitor dissolved solids, cyanides, phenols and dissolved oxygen.

The choice of segments, locations and sampling frequencies is based on an analysis of the preliminary design data in Figures 52, 53, 54 and 55. The results are summarized in Table 10. Choice of reach 30 for monitoring of dissolved solids is a foregone conclusion. The location is keyed to coincide with the location used to monitor phenols in reach 30, the Churchill Road Bridge at river mile 11.0. A weekly rate is selected (using Figure 5), since both phenols and dissolved solids have expected durations on the order of 7 days, and since weekly sampling is a very common sampling frequency [3]. Similarly, cyanides are monitored only in reach 21 at the Erie Railroad Bridge (river mile 30.6) just downstream of the preferred location. Once again the location coincides with monitoring of other parameters in reach 21 and the frequency is the commonly used weekly rate. The locations selected for monitoring of phenols are relatively arbitrary, given the number of segments indicating violations. Reach 30 is selected as the only reach in Pennsylvania with an expectation of phenols violations. Although Ohio's standard for phenols is assumed high for demonstration purposes, a number of segments appear to have problems with phenols, so monitoring is instituted in reaches 9 and 21, as a minimum system. The

Table 10. CANDIDATE 1.0 SAMPLING PROGRAM
(sampling interval in days, locations in river miles)

Reach	Dissolved Solids	Cyanides	Phenols	DO	Location
2				45	82.5
9			14		37.0
18				7	36.8
21		7	7	7	30.6[1]
30	7		7		11.0[2]
36				7	4.0[3]

Notes:

1. Erie Railroad Bridge
2. Churchill Road Bridge
3. 10th Street Bridge

frequency at reach 9 is set at 14 days, due to the expected violation duration and interval in that reach. Finally, monitoring for dissolved oxygen is to take place in reaches 2, 18, 21 and 36. Reach 2 is a reservoir, so it is assumed that monitoring of DO in reach 2 will take place from a boat at the preferred sampling location, RM 82.5. A low sampling rate is assumed, due to the long expected violation duration. Reach 21 is monitored in preference to reach 10, since other parameters are to be monitored there and since the preferred location in reach 10 is RM 31.0, the head of reach 21. The availability of the 10th Street Bridge in Reach 36 makes monitoring for DO there preferrable to monitoring in Reach 35.

For purposes of the demonstration, it is assumed that each state will monitor those segments of the Basin within its borders. Thus, the basic organizational framework shown in Figures 56, 57 and 58 is envisioned for the system means

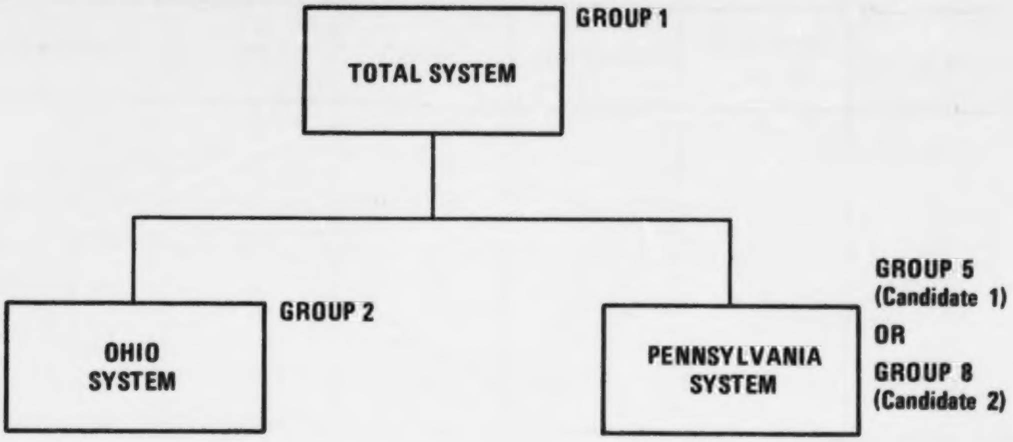

GROUP 1
TOTAL SYSTEM
OHIO SYSTEM
GROUP 2
PENNSYLVANIA SYSTEM
GROUP 5
(Candidate 1)
OR
GROUP 8
(Candidate 2)

Figure 56. Overall System Organizational Framework Assumed for All Candidates

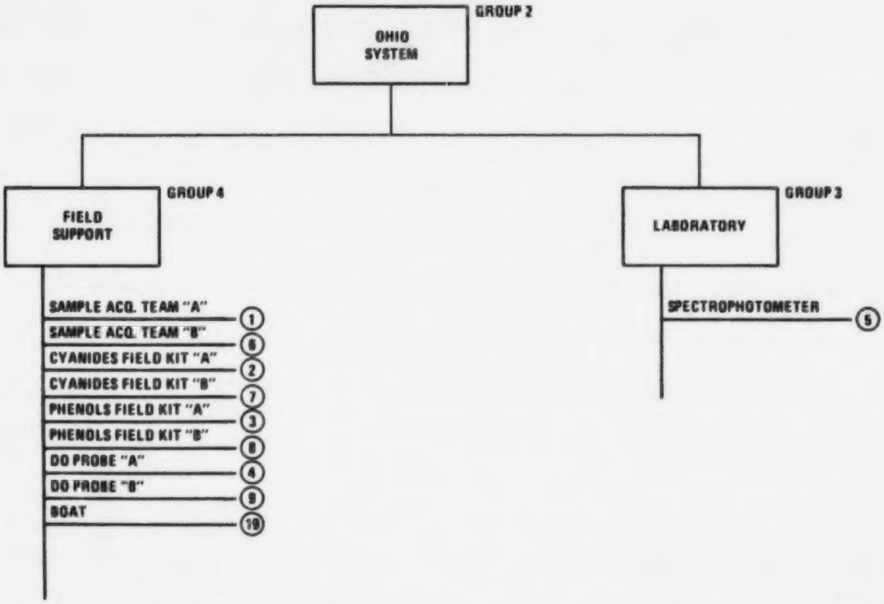

OHIO SYSTEM
GROUP 2
FIELD SUPPORT
GROUP 4
LABORATORY
GROUP 3
SAMPLE ACQ. TEAM "A"
①
SAMPLE ACQ. TEAM "B"
⑥
CYANIDES FIELD KIT "A"
②
CYANIDES FIELD KIT "B"
⑦
PHENOLS FIELD KIT "A"
③
PHENOLS FIELD KIT "B"
⑧
DO PROBE "A"
④
DO PROBE "B"
⑨
BOAT
⑩
SPECTROPHOTOMETER
⑤

Figure 57. Ohio System Organizational Framework Assumed for Candidate 1.0

listed in Table 11. Nineteen means are identified, including back-up equipment. Sample acquisition is to be performed by field teams traveling from site to site. Dissolved oxygen is to be monitored with a portable electrochemical monitor and dissolved solids estimated from conductivity measured with a portable monitoring instrument. Cyanides and phenols are to be determined using laboratory photometric techniques on samples prepared in the field for transportation. The functional framework of the system is shown in Figure 59 and summarized in the Utilization Table (Table 12).

The remainder of the required design data is summarized in Tables 13, 14 and 15. They are based on estimates by Raytheon personnel from their experience and are to be considered arbitrary. They are made solely for the purposes of the demonstration.

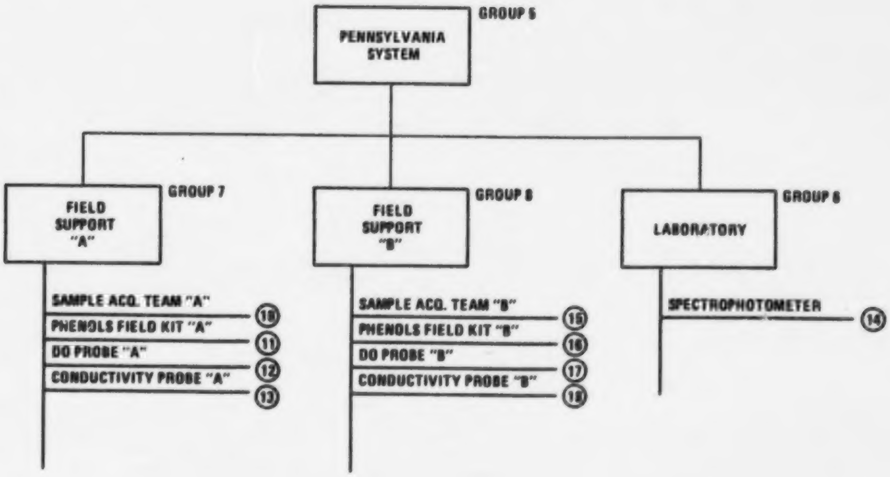

PENNSYLVANIA SYSTEM
GROUP 5
FIELD SUPPORT "A"
GROUP 7
FIELD SUPPORT "B"
GROUP 8
LABORATORY
GROUP 6
SAMPLE ACQ. TEAM "A"
⑩
PHENOLS FIELD KIT "A"
⑪
DO PROBE "A"
⑫
CONDUCTIVITY PROBE "A"
⑬
SAMPLE ACQ. TEAM "B"
⑮
PHENOLS FIELD KIT "B"
⑯
DO PROBE "B"
⑰
CONDUCTIVITY PROBE "B"
⑱
SPECTROPHOTOMETER
⑭

Figure 58. Pennsylvania System Organizational Framework Assumed for Candidate 1.0

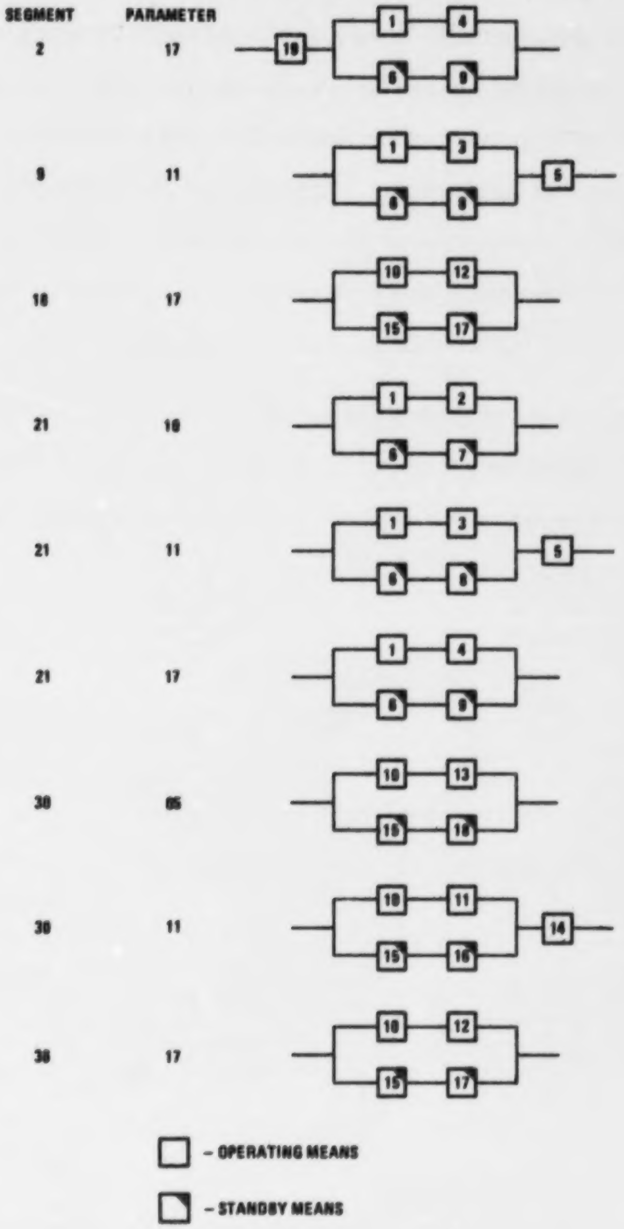

SEGMENT
PARAMETER
2
17
19
1
4
6
9
9
11
1
3
6
8
5
16
17
10
12
15
17
21
10
1
2
6
7
21
11
1
3
6
8
5
21
17
1
4
6
9
30
65
10
13
15
18
30
11
10
11
15
16
14
38
17
10
12
15
17
– OPERATING MEANS
– STANDBY MEANS

Figure 59. Functional Framework for Candidate 1.0

Table 11. SYSTEM MEANS FOR CANDIDATE 1.0

Means No.	State	Description
1	OH	Sample acquisition team "A" (incl. transp.)
2	OH	Cyanides Field Kit "A"
3	OH	Phenols Field Kit "A"
4	OH	DO Probe
5	OH	Spectrophotometer
6	OH	Sample acquisition team "B" (incl. transp.)
7	OH	Cyanides Field Kit "B"
8	OH	Phenols Field Kit "B"
9	OH	DO Probe "B"
10	PA	Sample acquisition team "A" (incl. transp.)
11	PA	Phenols Field Kit "A"
12	PA	DO Probe "A"
13	PA	Conductivity Probe "A"
14	PA	Spectrophotometer
15	PA	Sample acquisition team "B" (incl. transp.)
16	PA	Phenols Field Kit "B"
17	PA	DO Probe "B"
18	PA	Conductivity Probe "B"
19	OH	Small Boat and Dockage

Table 12. UTILIZATION TABLE FOR CANDIDATE 1.0

Segment Number	Parameter Number	Path Number	Normal Path States	Parallel Sub-Paths	Series Means in Path	Sub-Paths in Path
2	17	1	1	—	19	2, 3
		2	1	3	1, 4	—
		3	2	2	6, 9	—
9	11	1	1	—	5	2, 3
		2	1	3	1, 3	—
		3	2	2	6, 8	—
18	17	1	1	—	—	2, 3
		2	1	3	10, 12	—
		3	2	2	15, 17	—
21	10	1	1	—	—	2, 3
		2	1	3	1, 2	—
		3	2	2	6, 7	—
21	11	1	1	—	5	2, 3
		2	1	3	1, 3	—
		3	2	2	6, 8	—
21	17	1	1	—	—	2, 3
		2	1	3	1, 4	—
		3	2	2	6, 9	—
30	5	1	1	—	—	2, 3
		2	1	3	10, 13	—
		3	2	2	15, 18	—
30	11	1	1	—	14	2, 3
		2	1	3	10, 11	—
		3	2	2	15, 16	—
36	17	1	1	—	—	2, 3
		2	1	3	10, 12	—
		3	2	2	15, 7	—

Table 13. ASSUMED SAMPLING ERRORS FOR CANDIDATE 1.0

Parameter	Parameter Number	Accuracy ($\bar{\epsilon}$)	Precision (σ_ϵ)
Dissolved Solids	5	15.	15.
Cyanides	10	0.05	0.10
Phenols	11	0.001	0.002
Dissolved Oxygen	17	0.02	0.10

Table 14. ASSUMED FAILURE AND REPAIR RATES FOR CANDIDATE 1.0 (years^{-1})

Means No.	Survival Rate (Operating)	Survival Rate (Standby)	Failure Rate (Operating)	Failure Rate (Standby)	Repair Rate (Operating)	Repair Rate (Standby)
1	0.2	0.01	2.0	1.0	365.	365.
2	0.01	0.01	2.0	0.01	365.	365.
3	0.01	0.01	2.0	0.01	365.	365.
4	0.2	0.01	4.0	2.0	365.	365.
5	0.02	0.02	4.0	0.1	52.	52.
6	0.2	0.01	2.0	1.0	365.	365.
7	0.01	0.01	2.0	0.01	365.	365.
8	0.01	0.01	2.0	0.01	365.	365.
9	0.2	0.01	4.0	2.0	365.	365.
10	0.2	0.01	2.0	1.0	365.	365.
11	0.01	0.01	2.0	0.01	365.	365.
12	0.2	0.01	4.0	2.0	365.	365.
13	0.2	0.01	4.0	2.0	365.	365.
14	0.02	0.02	4.0	0.1	52.	52.
15	0.2	0.01	2.0	1.0	365.	365.
16	0.01	0.01	2.0	0.01	365.	365.
17	0.2	0.01	4.0	2.0	365.	365.
18	0.2	0.01	4.0	2.0	365.	365.
19	0.2	0.1	4.0	1.0	122.	122.

Table 15. ASSUMED COMPONENT COSTS FOR CANDIDATE 1.0 ($)

Means	Acquisition	Operation	Maintenance	Residual
1	3000.	5000.	400.	2000.
2	400.	500.	0.	0.
3	400.	500.	0.	0.
4	600.	10.	100.	300.
5	1500.	50.	0.	1500.
6	3000.	1000.	400.	2000.
7	400.	50.	0.	0.
8	400.	50.	0.	0.
9	600.	10.	100.	300.
10	3000.	5000.	400.	2000.
11	400.	500.	0.	0.
12	600.	10.	100.	300.
13	300.	10.	50.	150.
14	1500.	50.	0.	1500.
15	3000.	1000.	400.	2000.
16	400.	50.	0.	0.
17	600.	10.	100.	300.
18	300.	10.	50.	150.
19	1500.	100.	100.	1000.
Groups				
1	40000.	0.	0.	0.
2	10000.	5000.	0.	0.
3	20000.	4500.	1000.	20000.
4	5000.	2500.	500.	4500.
5	10000.	5000.	0.	0.
6	20000.	4500.	1000.	20000.
7	5000.	1500.	250.	4500.
8	5000.	1500.	250.	4500.

Also for purposes of the demonstration, it is assumed that all maintenance on the system can be scheduled during the intervals between sampling. That is, there is no routine maintenance downtime for Candidate 1.0.

Appendix G contains a complete listing of the design analysis program data deck for Candidate 1.0.

Candidate 2.0 —

In order to provide for direct comparison between Candidate 1.0 and Candidate 2.0, the same choice of monitored parameters and segments is used in both candidates. Table 16 summarizes the nominal characteristics of the Candidate 2.0 system. The very high sampling rate corresponds to an assumed hourly sampling interval for automated equipment. It is also assumed that the automatic equipment can be positioned at or very near the preferred sampling locations, with appropriate compromises being made when DO is sampled along with other parameters. Maintenance on the Candidate 2.0 equipment is performed weekly and takes six hours ($T_{up} = 6.75$ days, $T_{down} = 0.25$ days).

The organizational and functional frameworks for the means listed in Table 17 are shown in Figures 56, 60, 61 and 62. Each state is to operate its own telemetered remote monitoring system that transmits data to a central processing system for display. In addition, each monitoring station records the observations on an analog stripchart recorder for weekly collection by the maintenance personnel.

The assumed sampling errors, failure and repair rates, and system costs for Candidate 2.0 are presented in Tables 18, 19, and 20.

A complete listing of the design analysis data deck for Candidate 2.0 may be found in Appendix G.

Table 16. CANDIDATE 2.0 SAMPLING PROGRAM
(sampling interval in days, locations in river miles)

Reach	Dissolved Solids	Cyanides	Phenols	DO	Location
2				0.0417	82.5
9			0.0417		37.0
18				0.0417	36.8
21		0.0417	0.0417	0.0417	31.0
30	0.0417		0.0417		12.5
36				0.0417	7.8

Table 17. SYSTEM MEANS FOR CANDIDATE 2.0

Means No.	State	Description
21	PA	DO Monitor "1"
22	PA	Conductivity Monitor
23	PA	Phenols Monitor
24	PA	DO Monitor "2"
25	PA	Recorder "1"
26	PA	Service Team "1"
27	PA	Radio Telemetry Unit "1"
28	PA	Central Telemetry Unit
29	PA	Recorder "2"
31	OH	Cyanide Monitor
32	OH	Phenol Monitor "1"
33	OH	Phenol Monitor "2"
34	OH	DO Monitor "1"
35	OH	DO Monitor "2"
36	OH	Recorder "1"
37	OH	Paper Tape Punch
38	OH	Service Team
39	OH	Recorder "2"
40	OH	Telephone Telemetry Unit "1"
41	OH	Telephone System
42	OH	Central Telemetry Unit
43	OH	Recorder "3"
44	OH	Telephone Telemetry Unit "2"
50	PA	Radio Telemetry Unit "2"
51	PA	Recorder "3"
52	PA	Radio Telemetry Unit "3"
53	PA	Service Team "2"

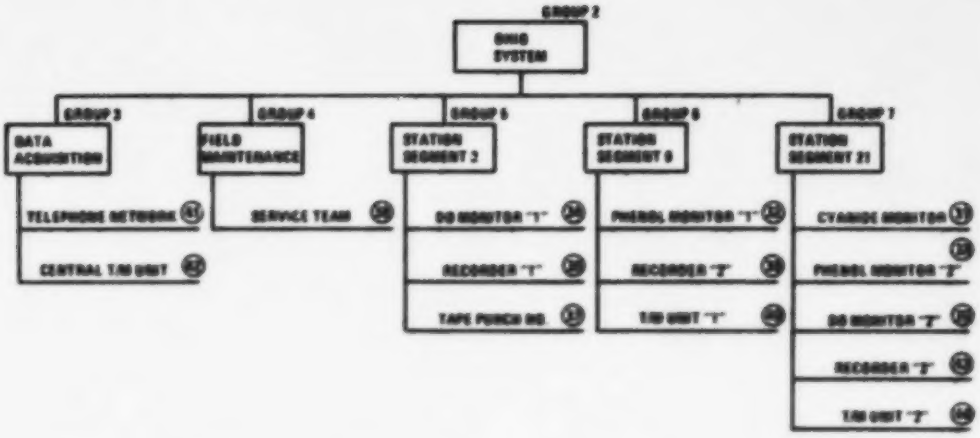

GROUP 2
OHIO SYSTEM
GROUP 3
DATA ACQUISITION
GROUP 4
FIELD MAINTENANCE
GROUP 5
STATION SEGMENT 2
GROUP 6
STATION SEGMENT 9
GROUP 7
STATION SEGMENT 21
TELEPHONE NETWORK
CENTRAL T/M UNIT
SERVICE TEAM
DO MONITOR "1"
RECORDER "1"
TAPE PUNCH RG.
PHENOL MONITOR "1"
RECORDER "2"
T/M UNIT "1"
CYANIDE MONITOR
PHENOL MONITOR "2"
DO MONITOR "2"
RECORDER "3"
T/M UNIT "2"

Figure 60. Ohio System Organizational Framework Assumed for Candidate 2.0

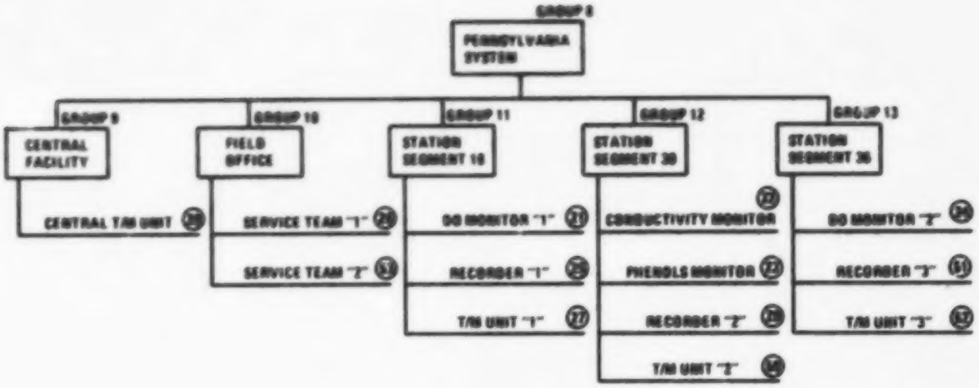

GROUP 8
PENNSYLVANIA SYSTEM
GROUP 9
CENTRAL FACILITY
GROUP 10
FIELD OFFICE
GROUP 11
STATION SEGMENT 10
GROUP 12
STATION SEGMENT 20
GROUP 13
STATION SEGMENT 36
CENTRAL T/M UNIT
SERVICE TEAM "1"
SERVICE TEAM "2"
DO MONITOR "1"
RECORDER "1"
T/M UNIT "1"
CONDUCTIVITY MONITOR
PHENOLS MONITOR
RECORDER "2"
T/M UNIT "2"
DO MONITOR "2"
RECORDER "3"
T/M UNIT "3"

Figure 61. Pennsylvania System Organizational Framework for Candidate 2.0

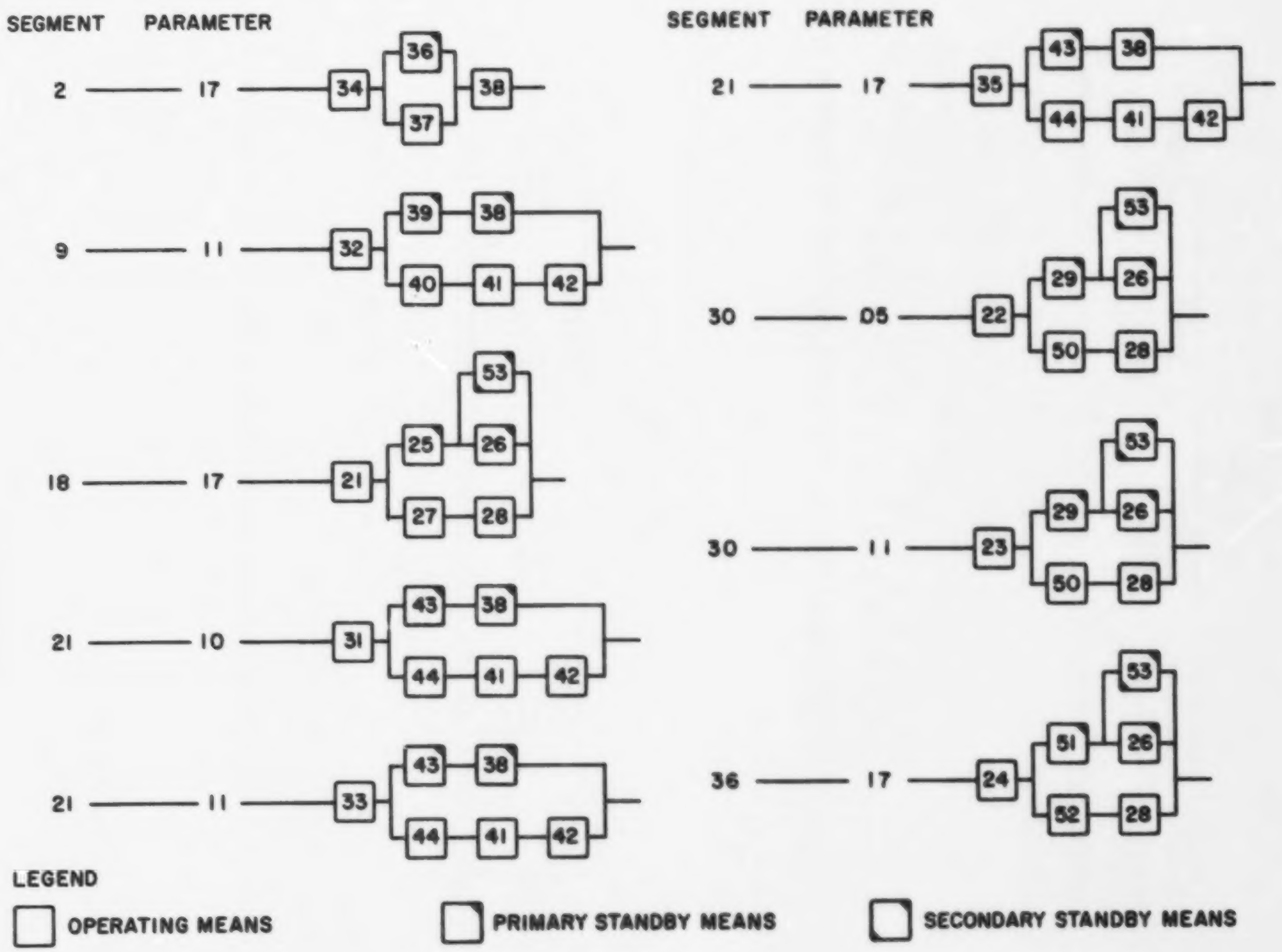

SEGMENT
PARAMETER
2
17
34
36
37
38
9
11
32
39
38
40
41
42
18
17
21
25
26
53
27
28
21
10
31
43
38
44
41
42
21
11
33
43
38
44
41
42
SEGMENT
PARAMETER
21
17
35
43
38
44
41
42
30
05
22
29
26
53
50
28
30
11
23
29
26
53
50
28
36
17
24
51
26
53
52
28
LEGEND
OPERATING MEANS
PRIMARY STANDBY MEANS
SECONDARY STANDBY MEANS

Figure 62. Functional Framework for Candidate 2.0

Table 18. ASSUMED SAMPLING ERRORS FOR CANDIDATE 2.0

Parameter	Parameter Number	Accuracy ($\bar{\epsilon}$)	Precision (σ_ϵ)
Dissolved Solids	5	15.	60.
Cyanides	10	0.02	0.15
Phenols	11	0.001	0.005
Dissolved Oxygen	17	0.05	0.15

Table 19. ASSUMED FAILURE AND REPAIR RATES FOR CANDIDATE 2.0 (years^{-1})

Means No.	Survival Rate (Operating)	Survival Rate (Standby)	Failure Rate (Operating)	Failure Rate (Standby)	Repair Rate (Operating)	Repair Rate (Standby)
21	0.2	0.01	5.0	365.	100.	365.
22	0.2	0.01	5.0	365.	100.	365.
23	0.2	0.01	6.0	365.	100.	365.
24	0.2	0.01	5.0	365.	100.	365.
25	0.2	0.01	3.0	0.3	100.	45.
26	0.01	0.01	2.0	0.5	365.	365.
27	0.2	0.01	5.0	1.	137.	137.
28	0.01	0.01	3.0	3.	365.	365.
29	0.2	0.01	3.0	0.3	100.	45.
31	0.2	0.01	6.0	365.	100.	365.
32	0.2	0.01	6.0	365.	100.	365.
33	0.2	0.01	6.0	365.	100.	365.
34	0.2	0.01	5.0	365.	100.	365.
35	0.2	0.01	5.0	365.	100.	365.
36	0.2	0.01	3.0	0.3	100.	45.
37	0.2	0.01	3.0	0.3	100.	45.
38	0.01	0.01	2.0	0.5	365.	365.
39	0.2	0.01	3.0	0.3	100.	45.
40	0.2	0.01	5.0	1.0	137.	137.
41	0.01	0.01	52.0	52.0	9999.	9999.
42	0.01	0.01	3.0	3.0	365.	365.
43	0.2	0.01	3.0	0.3	100.	45.
44	0.2	0.01	5.0	1.0	137.	137.
50	0.2	0.01	5.0	1.0	137.	137.
51	0.2	0.01	3.0	0.3	100.	45.
52	0.2	0.01	5.0	1.0	137.	137.
53	0.01	0.01	2.0	0.5	365.	365.

Table 20. ASSUMED COMPONENT COSTS FOR CANDIDATE 2.0

Means	Acquisition	Operation	Maintenance	Residual
21	1200.	200.	200.	900.
22	800.	100.	50.	600.
23	3500.	300.	350.	1800.
24	1200.	200.	200.	900.
5	1200.	20.	50.	900.
6	3000.	5000.	400.	2000.
27	7000.	400.	1000.	5500.
28	45000.	500.	1000.	35000.
29	1200.	20.	50.	900.
31	3500.	300.	350.	1800.
32	3500.	300.	350.	1800.
33	3500.	300.	350.	1800.
34	1200.	200.	200.	900.
35	1200.	200.	200.	900.
36	1200.	20.	50.	900.
37	1800.	20.	50.	1000.
38	3000.	5000.	400.	2000.
39	1200.	20.	50.	900.
40	4500.	400.	900.	3800.
41	0.	12000.	0.	0.
42	40000.	400.	1000.	35000.
43	1200.	20.	50.	900.
44	4500.	400.	900.	3800.
50	7000.	400.	1000.	5500.
51	1200.	20.	50.	900.
52	7000.	400.	1000.	5500.
53	3000.	5000.	400.	2000.
Groups				
1	40000.	0.	0.	0.
2	10000.	5000.	0.	0.
3	20000.	1000.	0.	20000.
4	5000.	2500.	500.	4500.
5	1000.	150.	350.	150.
6	1000.	150.	350.	150.
7	1000.	150.	350.	150.
8	10000.	5000.	0.	0.
9	20000.	1000.	0.	20000.
10	5000.	2500.	500.	4500.
11	1000.	150.	350.	150.
12	1000.	150.	350.	150.
13	1000.	150.	350.	150.

Task 5 - Candidate Evaluation

The evaluation of Candidates 1.0 and 2.0 is performed using the design analysis programs in the final design mode. As previously mentioned, the input data decks are listed in Appendix G. The resulting computer print-outs may also be found in Appendix G.

Tables 21 and 22 summarize the results of the cost-effectiveness computer runs for Candidate 1.0 and 2.0, respectively. The data in each table are rounded to 3 decimal places.

Table 21. SUMMARY COST-EFFECTIVENESS RESULTS FOR CANDIDATE 1.0

Parameter	Segment	Capability	Survivability	Availability	$n_d{}^*$
5	30	0.004	0.936	1.000	0.003
10	21	0.017	0.979	1.000	0.017
11	9	0.009	0.960	0.929	0.008
11	21	0.001	0.960	0.929	0.001
11	30	0.006	0.960	0.929	0.005
17	2	0.001	0.766	0.968	0.001
17	18	0.017	0.936	1.000	0.016
17	21	0.017	0.936	1.000	0.016
17	36	0.017	0.936	1.000	0.016

$E_{sys} = 0.151$

$K_{sys} = \$1.535 \cdot 10^5$

$\Gamma_{1.0} = 10.162 \cdot 10^5$

Table 22. SUMMARY COST-EFFECTIVENESS RESULTS FOR CANDIDATE 2.0

Parameter	Segment	Capability	Survivability	Availability	n_d^*
5	30	0.008	0.981	0.999	0.007
10	21	0.034	0.980	0.978	0.032
11	9	0.036	0.980	0.978	0.035
11	21	0.010	0.980	0.978	0.010
11	30	0.009	0.981	0.999	0.009
17	2	0.009	0.796	0.947	0.007
17	18	0.031	0.981	0.999	0.031
17	21	0.000	0.980	0.978	0.000
17	36	0.030	0.981	0.999	0.030

$$E_{sys} = 0.292$$

$$K_{sys} = \$2.005 \cdot 10^5$$

$$\Gamma_{2.0} = 6.864 \cdot 10^5$$

Task 6 - Design Selection

In an actual design analysis, the next step is the selection of one of the candidates, or alternatively the design of new candidates, on the basis of the analysis results.

If the objective is to select one of the two candidates, the separate acceptability of E_{sys} and K_{sys} must first be considered. Then the comparison for cost-effectiveness made.

The effectiveness of both candidates is relatively low, while the costs for the one-year system duration seem within reason. The high frequency sampling of the Candidate 2.0 system does have a clear advantage over the low frequency Candidate 1.0 system, yielding almost twice the effectiveness. Yet the Candidate 1.0 system stands up reasonably well, when one considers that the sampling rate of Candidate 2.0 is about 200 times greater.

If it is assumed that both effectiveness ratings are acceptable, then the choice goes to Candidate 2.0 on the basis of a lower cost/effectiveness ratio (Γ). It should be noted that Candidate 2.0 is the more costly of the two. It is the higher system effectiveness of Candidate 2.0 that makes it the "better" system.

This seems an appropriate point to remind the reader of the caveat at the beginning of the Section. These results are entirely a function of the assumptions of the demonstration. They should not be interpreted as a recommendation of Candidate 2.0 for use in the Beaver River Basin.

ADDITIONAL CANDIDATES

A more likely course of action for the system designer during Task 6 would be rejection of both candidates on the basis of the low effectiveness ratings. The next step would be to return to Task 4 and design additional candidates with the intention of improving the performance. The following paragraphs explore some possible candidates that might result from such a decision.

Candidate 1.1

In attempting to improve the effectiveness of Candidate 1.0, the system designer examines the analysis results for points of poor performance. Capability is the prime cause of the low effectiveness associated with Candidate 1.0 (Table 21). In most cases the sampling interval used in Candidate 1.0 is near the expected duration of the violations. It might be expected that an improvement would result from increased sampling in some reaches, especially in the light of the analysis results for Candidate 2.0. Other stations might be eliminated altogether, due to low effectiveness.

Candidate 1.1 is designed using Candidate 1.0 as a basis. The sampling intervals are changed to the values indicated in Table 23, while the costs are adjusted upwards or downwards to match the increased or decreased sampling (Table 24). Appendix G presents a complete listing of the data deck for Candidate 1.1.

The analysis results for Candidate 1.1 are shown in Table 25.

It can be seen that Candidate 1.1 represents a real improvement over Candidate 1.0, although it is still not as good as Candidate 2.0. Despite the elimination of sampling for phenols at reach 21 and the doubling of the DO sampling interval at reach 2, the new effectiveness is only 0.051 greater than the Candidate 1.0 effectiveness (E_{sys}). Since cost is only slightly increased, due to cost reductions at those two system elements, the cost-effectiveness ratio is significantly improved.

Candidate 2.1

In the examination of Candidate 2.0 analysis results, the system designer might particularly note the very low capability associated with the DO monitor in reach 21. The designer might conclude that the station is misplaced, since the high sampling rate of Candidate 2.0 should assure that it would detect any violation occurring at the monitoring point.

The conclusion is correct. The intent was to monitor the DO at the downstream end of reach 10 by placing the station at the head of reach 21. However, Mosquito Creek joins the Mahoning at reach 21, contributing relatively high DO waters. Computationally, the math model incorporates the addition by pro-

Table 23. CANDIDATE 1.1 SAMPLING PROGRAM
(sampling interval in days, locations in river miles)

Reach	Dissolved Solids	Cyanides	Phenols	DO	Location
2				90	82.5
9			7		37.0
18				7	36.8
21		3.5		3.5	30.6
30	3.5		3.5		11.0
36				7	4.0

Table 24. ASSUMED COMPONENT COSTS FOR CANDIDATE 1.1

Means	Acquisition	Operation	Maintenance	Residual
1	3000.	10000.	600.	2000.
2	400.	1000.	0.	0.
3	400.	500.	0.	0.
4	600.	20.	200.	300.
5	1500.	50.	0.	1500.
6	3000.	1000.	400.	2000.
7	400.	50.	0.	0.
8	400.	50.	0.	0.
9	600.	10.	100.	300.
10	3000.	7000.	400.	2000.
11	400.	1000.	0.	0.
12	600.	10.	100.	300.
13	300.	20.	100.	150.
14	1500.	50.	0.	1500.
15	3000.	1000.	400.	2000.
16	400.	50.	0.	0.
17	600.	10.	100.	300.
18	300.	10.	50.	150.
19	1500.	200.	100.	1000.
Group				
1	40000.	0.	0.	0.
2	10000.	5000.	0.	0.
3	20000.	4500.	1000.	20000.
4	5000.	2500.	500.	4500.
5	10000.	5000.	0.	0.
6	20000.	4500.	1000.	20000.
7	5000.	1500.	250.	4500.
8	5000.	1500.	250.	4500.

ducing two different DO values for RM 7.8, one at the downstream end of reach 10 and the other at the upstream end of reach 21.

Table 25. SUMMARY COST-EFFECTIVENESS RESULTS FOR CANDIDATE 1.1

Parameter	Segment	Capability	Survivability	Availability	n_d^*
5	30	0.006	0.936	1.000	0.005
10	21	0.025	0.979	1.000	0.025
11	9	0.020	0.960	0.929	0.017
11	30	0.007	0.960	0.929	0.006
17	2	0.000	0.766	0.968	0.000
17	18	0.017	0.936	1.000	0.016
17	21	0.027	0.936	1.000	0.025
17	36	0.017	0.936	1.000	0.016

$$E_{sys} = 0.202$$

$$K_{sys} = \$1.619 \cdot 10^5$$

$$\Gamma_{1.1} = 8.013 \cdot 10^5$$

Thus, both computationally and in actuality the stream monitor should be placed upstream of the stream junction to detect DO violations in reach 10.

Table 26 presents the analysis results for Candidate 2.1. The new candidate is identical with Candidate 2.0, except that the DO monitor is moved to reach 10, RM 7.8. (See Appendix G for a data deck listing.) The result is a slight improvement in system effectiveness with the associated improvement in cost-effectiveness. Since costs have not been revised to reflect the need for additional equipment to support the relocated monitor, the actual cost-effectiveness would be somewhat poorer than that shown in Table 26.

Table 26. SUMMARY COST-EFFECTIVENESS RESULTS FOR CANDIDATE 2.1

Parameter	Segment	Capability	Survivability	Availability	n_d^*
5	30	0.007	0.981	0.999	0.007
10	21	0.034	0.980	0.978	0.032
11	9	0.036	0.980	0.978	0.035
11	21	0.010	0.980	0.978	0.010
11	30	0.009	0.981	0.999	0.009
17	2	0.009	0.796	0.947	0.007
17	10	0.002	0.980	0.978	0.002
17	18	0.031	0.981	0.999	0.031
17	36	0.030	0.981	0.999	0.030

$$E_{sys} = 0.296$$

$$K_{sys} = \$2.005 \cdot 10^5$$

$$\Gamma_{2.1} = 6.777 \cdot 10^5$$

Design Selection

With the additional analyses the system designer is in a better position to evaluate his candidates and select one. It appears on the basis of the results contained in Tables 21, 22, 25 and 26 that, of those examined, Candidate 2.0 remains the preferred design for a one-year system duration under the demonstration assumptions. While Candidate 1.1 is an improvement over Candidate 1.0, it is still inferior to Candidates 2.0 and 2.1.

The system designer may wish to perform one more iteration before settling on Candidate 2.0, however. Since there is little improvement when the DO monitor is moved from reach 21 to reach 10, it might be of interest to examine a candidate similar to candidate 2.0, but without DO monitoring in either reach 10 or 21. It is left to the interested reader to pursue this line of reasoning. Sufficient information may be found in the tables and Appendix G to permit a manual computation of the change in E_{sys} and K_{sys}.

FURTHER ILLUSTRATION

In addition to the points demonstrated in the preceeding, there are several other factors worthy of illustration. One of these is the effect of choice of flow record length. Another is the effect of increased system duration. The third is the potential for improved system effectiveness through additional monitoring. Each of these factors is discussed in the following paragraphs.

Length of Flow Record

The estimation of effectiveness depends on estimates for the T_0's and T_1's, that are, in turn, derived from USGS gaging station flow data. The length of the record used in the analysis affects the results in two ways. For those reaches in which the river is either constantly in violation state or constantly in non-violation state, the value of $n_v{}^{**}$ is a function of the record length. For those cases either $T_0{}^{**}$ or $T_1{}^{**}$ is equal to the record length, the other is zero, and equation (21) reduces to either:

$$n_v{}^{**}(i,j) = \frac{1}{T_0{}^{**}(i,j)} \tag{42}$$

or

$$n_v{}^{**}(i,j) = \frac{1}{T_1{}^{**}(i,j)} \tag{43}$$

The other effect of the record length is in the estimation T_0's and T_1's for reaches with low variability. Since these expected durations are computed as averages (equation (41)), the quality of the estimate improves as the number of events increases. The number of events included in the averages is, in turn, a function of the flow record length.

Thus, the system designer might wish to question the stability of the analysis results as a function of USGS gaging station record length.

To answer the question for Candidate 1.0 and to illustrate the general case, three analysis of Candidate 1.0 are run. The three analyses are for record lengths of 4, 5 and 6 years, respectively. The resulting system effectiveness for each case is listed in Table 27. Some trend toward increased E_{sys} with increased record length can be seen, due primarily to the reduction in n_v**. The results are relatively stable, however, despite the 20% changes in record length.

Table 27. EFFECT OF FLOW RECORD LENGTH ON E_{sys}

(Candidate 1.0)

Record Length (years)	E_{sys}
4	0.141
5	0.151
6	0.159

Thus, comparison of candidate systems analyzed using the same flow record is unaffected by the absolute length of the flow record, as long as it is sufficiently long to include several violation events. This is due to the use of the same values for n_v** in each calculation of E_{sys}.

In addition, the absolute value of cost-effectiveness is relatively stable for large changes in the flow record length. Table 27 would suggest a variation of about 5% for record length changes on the order of 20%.

Increased System Duration

Unlike the flow record length, the choice of system duration may be expected to have a major effect on the analysis results. As system duration increases, candidates with large ratio of fixed costs to variable costs will have an increased advantage over candidates with low ratios. That is, systems that operate with the largest proportion of their costs in the operation and maintenance categories will tend to increase total cost faster than those with a predominance of the acquisition cost.

Since such clear-cut distinctions are difficult to make in the demonstration candidates used previously in this section, the system designer cannot, a priori, decide which will be the better system for a longer system duration. Use of the analysis programs does provide the answer.

Candidates 1.2 and 2.2 are created from Candidates 1.1 and 2.1, respectively, to test the effect of increased system duration. The major change in the data decks (see listings in Appendix G) is the adjustment of the cost data. The operating and maintenance budgets are increased by a factor of 5 to correspond to a 5-year system duration. In addition, appropriate changes are made whenever replacement of equipment is anticipated. For example, allowance is made to supply field crews with new vehicles during the system duration.

The analysis results for Candidates 1.2 and 2.2 are summarized in Tables 28 and 29.

Table 28. SUMMARY COST-EFFECTIVENESS RESULTS FOR CANDIDATE 1.2

Parameter	Segment	Capability	Survivability	Availability	n_d^*
5	30	0.006	0.393	1.000	0.002
10	21	0.025	0.700	1.000	0.018
11	9	0.020	0.633	0.929	0.011
11	30	0.007	0.633	0.929	0.004
17	2	0.000	0.145	0.968	0.000
17	18	0.017	0.393	1.000	0.007
17	21	0.027	0.393	1.000	0.010
17	36	0.017	0.393	1.000	0.007

$$E_{sys} = 0.108$$

$$K_{sys} = \$4.367 \cdot 10^5$$

$$\Gamma_{1.2} = 40.302 \cdot 10^5$$

$$\Gamma_{annual} = 8.060 \cdot 10^5$$

The results are as expected. The total system costs are increased and the system effectiveness is decreased due to the possibility of irrecoverable failure. In the case of Candidate 1.2, the effectiveness is about 1/2 that of Candidate 1.1. For Candidate 2.2, E_{sys} is about 2/3 of the value for Candidate 2.1. The value of the cost-effectiveness ratio gives Candidate 2.2 the clear advantage over Candidate 1.2, despite a $100,000 difference in total cost.

The reader is reminded once again that these results are a function of the arbitrary data used in this demonstration. Unwarranted conclusions about real systems should not be drawn.

In order to compare these candidates with the previous candidates designed for one-year system duration, a factored cost-effectiveness can be computed. By divising the Γ's for Candidates 1.2 and 2.2 by a factor of 5, an average annual Γ can be computed, as shown in Tables 28 and 29. As expected, the automatic system

$$E_{sys} = 0.212$$

$$K_{sys} = \$5.564 \cdot 10^5$$

$$\Gamma_{2.2} = 26.190 \cdot 10^5$$

$$\Gamma_{annual} = 5.238 \cdot 10^5$$

(Candidate 2.2), with its higher initial investment and lower operating and maintenance costs, comes out ahead, when compared with Candidates 1.1, 1.2, and 2.1 on an annual basis.

Table 29. SUMMARY COST-EFFECTIVENESS RESULTS FOR CANDIDATE 2.2

Parameter	Segment	Capability	Survivability	Availability	n_d^*
5	30	0.008	0.726	1.000	0.006
10	21	0.034	0.717	0.978	0.024
11	9	0.036	0.717	0.978	0.025
11	21	0.010	0.717	0.978	0.007
11	30	0.009	0.726	0.999	0.006
17	2	0.009	0.254	0.947	0.002
17	10	0.002	0.717	0.978	0.002
17	18	0.031	0.726	0.999	0.023
17	36	0.030	0.726	0.999	0.022

Additional Monitoring

Finally, the system designer might wish to explore the effects of increased monitoring of the basin. General results of implementing monitoring in additional segments cannot be predicted. The result for the Beaver River Basin can be used as an illustration of a specific case, however.

Candidate 2.3 is developed from Candidate 2.2 by implementing additional monitoring for phenols and dissolved oxygen. The additional sampling is detailed in Table 30. The additional organizational and functional frameworks are specified in Figures 63, 64 and 65 for the additional means listed in Table 31. A complete listing of the data deck for Candidate 2.3 can be found in Appendix G.

The analysis results for Candidate 2.3 are summarized in Table 32.

A tremendous improvement in the system effectiveness and cost-effectiveness ratio is achieved by this additional monitoring. The E_{sys} jumps from about 20% for Candidate 2.2 to nearly 60% for Candidate 2.3. Costs are, of course, greater, but the improved effectiveness reduces Γ from about $26 \cdot 10^5$ to about $12 \cdot 10^5$. On an annual basis, this is equivalent to a cost-effectiveness ratio of about $2.4 \cdot 10^5$, the best Γ achieved by any of the candidates examined.

Thus, it would appear that, if a budget of $\$7.23 \cdot 10^5$ over five years is acceptable, Candidate 2.3 is the choice of the system designer (within the limits of the demonstration).

FINAL COMMENTS

The demonstration cases examined in this section suggest the utility of the design analysis programs from a performance viewpoint.

Table 30. CANDIDATE 2.3 SAMPLING PROGRAM
(sampling interval in days, locations in river miles)

Reach	Dissolved Solids	Cyanides	Phenols	DO	Location
2				0.0417	82.5
9			0.0417		37.0
10				0.0417	31.0
16			0.0417		44.8
17				0.0417	42.4
18				0.0417	36.8
19				0.0417	35.6
21		0.0417	0.0417		31.0
24			0.0417		23.5
27			0.0417		18.5
28			0.0417		16.5
29			0.0417		15.5
30	0.0417		0.0417		12.5
35				0.0417	7.8
36				0.0417	4.6

Weighted against their utility is the cost of using the computer programs. The time occupied in the preparation of the candidate system designs and data decks is of course, a function of the system designer and the facilities available to him. The computer run times are a function of the machine used and the programming.

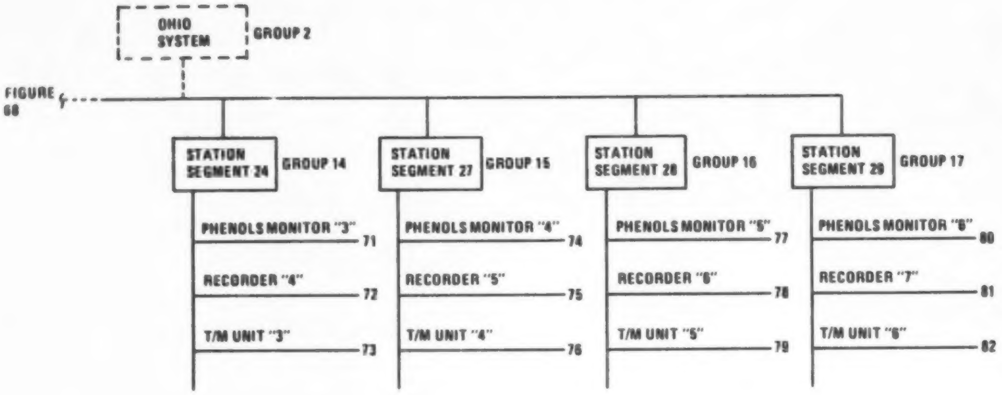

OHIO
SYSTEM
GROUP 2
FIGURE 68
STATION SEGMENT 24
GROUP 14
STATION SEGMENT 27
GROUP 15
STATION SEGMENT 28
GROUP 16
STATION SEGMENT 29
GROUP 17
PHENOLS MONITOR "3"
71
RECORDER "4"
72
T/M UNIT "3"
73
PHENOLS MONITOR "4"
74
RECORDER "5"
75
T/M UNIT "4"
76
PHENOLS MONITOR "5"
77
RECORDER "6"
78
T/M UNIT "5"
79
PHENOLS MONITOR "6"
80
RECORDER "7"
81
T/M UNIT "6"
82

Figure 63. Additional Ohio Organizational Framework Assumed for Candidate 2.3

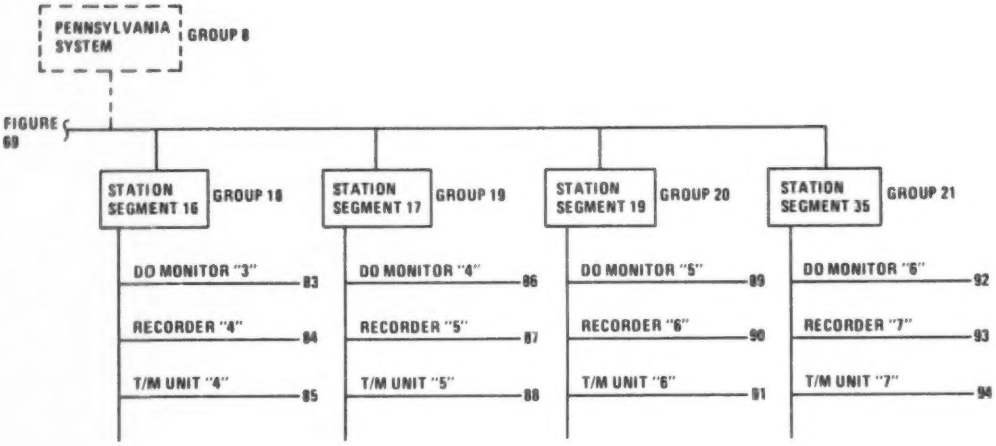
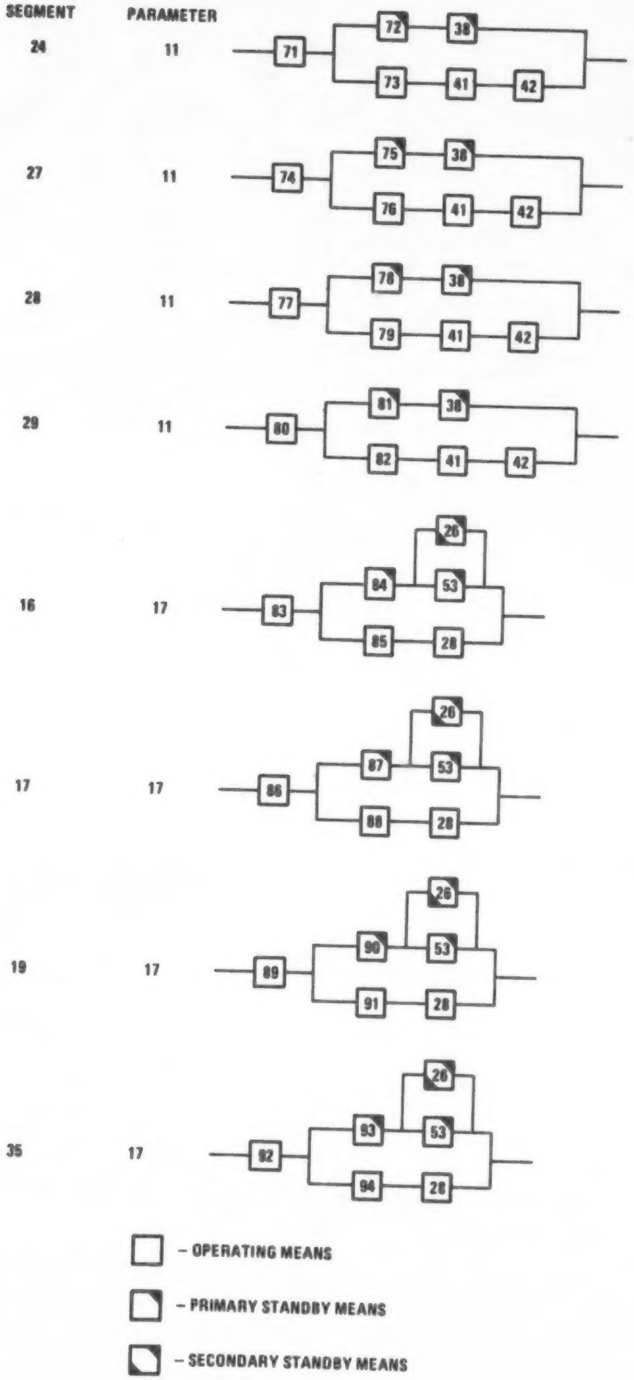

PENNSYLVANIA
SYSTEM
GROUP 8
FIGURE 69
STATION SEGMENT 16
GROUP 18
STATION SEGMENT 17
GROUP 19
STATION SEGMENT 19
GROUP 20
STATION SEGMENT 35
GROUP 21
DO MONITOR "3"
83
RECORDER "4"
84
T/M UNIT "4"
85
DO MONITOR "4"
86
RECORDER "5"
87
T/M UNIT "5"
88
DO MONITOR "5"
89
RECORDER "6"
90
T/M UNIT "6"
91
DO MONITOR "6"
92
RECORDER "7"
93
T/M UNIT "7"
94

Figure 64. Additional Pennsylvania Organizational Framework Assumed for Candidate 2.3


SEGMENT
PARAMETER
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28
– OPERATING MEANS
– PRIMARY STANDBY MEANS
– SECONDARY STANDBY MEANS

Figure 65. Additional Functional Framework for Candidate 2.3

Table 31. ADDITIONAL SYSTEM MEANS FOR CANDIDATE 2.3

Means No.	State	Same Type of Equipment as Means No. *
71	OH	32
72	OH	36
73	OH	40
74	OH	32
75	OH	36
76	OH	40
77	OH	32
78	OH	36
79	OH	40
80	OH	32
81	OH	36
82	OH	40
83	PA	34
84	PA	36
85	PA	27
86	PA	34
87	PA	36
88	PA	27
89	PA	34
90	PA	36
91	PA	27
92	PA	34
93	PA	36
94	PA	27

*Implies the use of the same cost and reliability/maintainability data.

Table 32. SUMMARY OF COST-EFFECTIVENESS RESULTS FOR CANDIDATE 2.3

Parameter	Segment	Capability	Survivability	Availability	n_d^*
5	30	0.008	0.726	0.999	0.006
10	21	0.034	0.717	0.978	0.024
11	9	0.036	0.717	0.978	0.025
11	21	0.010	0.717	0.978	0.007
11	24	0.042	0.717	0.978	0.030
11	27	0.004	0.717	0.978	0.003
11	28	0.046	0.717	0.978	0.032
11	29	0.056	0.717	0.978	0.039
11	30	0.035	0.726	0.999	0.025
17	2	0.009	0.254	0.947	0.002
17	10	0.002	0.717	0.978	0.002
17	16	0.002	0.726	0.999	0.002
17	17	0.021	0.726	0.999	0.015
17	18	0.031	0.726	0.999	0.023
17	19	0.047	0.726	0.999	0.034
17	35	0.030	0.726	0.999	0.022
17	36	0.050	0.726	0.999	0.036

$E_{sys} = 0.593$

$K_{sys} = \$7.238 \cdot 10^5$

$\Gamma_{2.3} = 12.196 \cdot 10^5$

$\Gamma_{annual} = 2.439 \cdot 10^5$

Typical computation times on the CDC 6700 ranged from about 3 min CPU time for the preliminary design run to 5 min CPU time for the final design analysis of Candidate 2.3. In practice, the authors found that, given the basic data deck, a candidate could be revised, the data deck modified and the analysis results computed in the span of two hours (during the evening shift on Raytheon's CDC 6700). Preparation of the basic data deck, of course, required a substantially longer time, due primarily to the keypunching requirement. Excluded from consideration here is the labor involved in calibrating the RIBAM model. See [7] for an understanding of that process.

The computation times mentioned above are quite long and constitute a substantial dollar cost. When compared with the potential cost of performing the design analysis manually, they are quite acceptable, if used with discretion.

The system designer may wish to take due precautions to assure that the data deck, especially the last files (e.g., COSTM and COSTG), are correct before submission for a run. Errors in the data deck frequently cause termination of the run before the final results are printed, causing loss of information from analysis of the correct portions of the data deck. Such loss can be expensive, if it occurs near the end of a 5 min run.

SECTION IX

DISCUSSION

The water quality surveillance system design methods developed in [3] and in this report constitute a fundamental approach to the engineering of in-stream monitoring systems. They incorporate all the major factors influencing the system designer in his selection of design options and provide reasonable guidelines for the assessment of those factors for a given river basin.

The procedures have been successfully demonstrated on the Wabash River Basin [3] and on the Beaver River Basin. The results of the demonstration analyses seem consistent with our understanding of river processes and systems performance. The definition of system effectiveness presented in equation (14) appears to have significance in the present context of in-stream monitoring. As illustrated in the demonstration, it is sensitive to changes in the basic system characteristics and provides the system designer with useful information to guide the iterative development of his design. The demonstration also suggests that the computerization of the design methods substantially satisfies the goals of drawing on the existing basin modeling capabilities and reducing the labor involved in evaluation of candidate systems. The costs of computer usage are very reasonable when considered in the light of the alternatives.

However, the methods developed in this report do not constitute a complete analysis of the design problem. As indicated in Section VI and [3], a number of lesser design factors have been neglected in the effort to develop a beginning-to-end approach incorporating the more important considerations. Furthermore, a number of simplifying assumptions and pragmatic substitutions have been used, when required, to by-pass particularly knotty problems. While the approach as

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a whole performs well in the demonstration, each of these artifices should be subject to further confirmation.

In the development of these methods, emphasis has been placed on the theoretical and functional aspects. It is not claimed that the computer programs are fully optimized. In the context of a development project, the authors are satisfied that they correctly perform the necessary computations without requiring either excessive storage or CPU time.

In addition, real application of the method in the near future may be expected to suffer from limitations on cost and reliability data. Experience and the literature (e.g., the extensive review in [28]) suggest that the techniques and instruments employed for water quality surveillance have a history of questionable performance in these areas. Detailed analyses of their performance are not available, in general. Considering the extent of surveillance required to implement the current legislation [1], development of a data base to support cost-effectiveness analysis appears entirely in order. It seems entirely within the prerogatives of the governmental agencies engaged in water quality surveillance to develop such a capability. The water quality surveillance called for in [1] is, of course, not confined to in-stream monitoring. The emphasis is shared with direct monitoring of point-source effluents. Similar development of systems analysis methods should be aimed at the effluent monitoring sector of the surveillance system. Since effluent monitoring and in-stream monitoring constitute complementary parts of a total surveillance capability, future development of system design methods should optimize total system performance through compatible use of both monitoring strategies.

In conclusion, the worth of these methods will be proven in the application. The authors fully expect that each user will have his own contribution to make to the design methods. The computer programs are not immutable; they should be used as a tool and modified as appropriate to the situation. Likewise, the methods will benefit from the experience gained through application in a variety of river basins.

SECTION X

REFERENCES

[1] Public Law 92-500, Federal Water Pollution Control Act, Sections 101 (a) and 104 (a) (5) (1972).

[2] Sayers, W.T. Water Quality Surveillance. Environmental Science and Technology. 5 (2), February 1971.

[3] Beckers, C.V., S.G. Chamberlain, and G.P. Grimsrud. Quantitative Methods for Preliminary Design of Water Quality Surveillance Systems. Environmental Protection Agency, Washington, DC. Report No. EPA-R5-72-001. November 1972. 226 p.

[4] Ward, R.C. Data Acquisition Systems in Water Quality Management. Environmental Protection Agency, Washington, DC. Report No. EPA-R5-73-014. May 1973. 259 p.

[5] NUS Corporation. Design of Water Quality Surveillance Systems. US Dept of the Interior, Federal Water Quality Administration, Washington, DC. Report No. 16090 DBJ 08/70. August 1970. 302 p.

[6] Moore, S.F. Estimation Theory Applications to Design of Water Quality Monitoring Systems. Jour. Hydr. Div., Proc. ASCE. 99 (HY5): 815-831, May 1973.

[7] Raytheon Company. Documentation Report, Beaver River Basin Model Project. Environmental Protection Agency, Washington, DC. Draft Report, Contract No. 68-01-0746. March 1973. Vols. I and II, 531 p.

[8] Public Law 92-500, Federal Water Pollution Control Act Amendments of 1972, 86 STAT 816 et. seq., October 18, 1973.

[9] Committee on Public Works, US House of Representatives. Laws of the United States Relating to Water Pollution Control and Environmental Quality. US Government Printing Office, Washington, DC. July 1970. 265 p.

[10] Vanderholm, D.H. Planning Water Quality Surveillance. Dept. of Agricultural Engineering, Colorado State University. Ph.D. Dissertation. 1972. 148 p.

[11] Texas Water Development Board. DOSAG-1, Simulation of Water Quality in Streams and Canals, Program Documentation and User's Manual. Report No. PB 202 974. September 1970.

Preceding page blank

[12] Seiler, K. Introduction to Systems Cost Effectiveness. New York, Wiley-Interscience, 1969. 108 p.

[13] Sandler, G.H. System Reliability Engineering. Englewood Cliffs, Prentice-Hall, 1963. 221 p.

[14] Goldman, A.S., and T.B. Slattery. Maintainability: A Major Element of System Effectiveness. New York, John Wiley & Sons, Inc., 1964, 282 p.

[15] Grant, E.L., and W.G. Ireson. Principles of Engineering Economy, 4th ed. New York, The Ronald Press Co., 1960. 574 p.

[16] English, J.M., ed. Cost Effectiveness—the Economic Evaluation of Engineered Systems. New York, John Wiley & Sons, Inc., 1968. 301 p.

[17] Helstrom, C.W. Statistical Theory of Signal Detection. New York, Pergamon Press, 1960. 364 p.

[18] Raytheon Company. Data Report, Beaver River Basin Model Project. Environmental Protection Agency, Washington, DC. Draft Report, Contract No. 68-01-0746. November 1972.

[19] Feinstein, A. Foundations of Information Theory. New York, McGraw-Hill, 1958. 137 p.

[20] International Mathematical and Statistical Libraries, Inc. IMSL Library 3 Reference Manual, 2nd ed. Houston. December 1972.

[21] Texas Water Development Board. QUAL-1, Simulation of Water Quality in Streams and Canals, Program Documentation and Users Manual. September, 1970.

[22] Texas Water Development Board. Simulation of Water Quality in Streams and Canals. Theory and Description of the QUAL-1 Mathematical Modeling System. May 1971.

[23] Environmental Protection Agency, Water Quality Office. Storm Water Management Model. Washington, DC. September 1971. Vol. I, II, III & IV.

[24] Water Resources Engineers, Inc. Mathematical Models for the Prediction of Thermal Energy Changes in Impoundments. Environmental Protection Agency, Washington, DC. December 1969.

[25] Water Resources Engineers, Inc. Mathematical Models for the Prediction of Thermal Energy Changes in Impoundments, Computer Application Supplement. Federal Water Pollution Control Administration, Columbia River Thermal Effects Project.

[26] Environmental Protection Agency, Region X, Pacific Northwest Laboratory. User's Guide and Documentation for Outfall PLUME Model. Working Paper No. 80. May 1971.

[27] Feigner, K. D., and H. S. Harris. Documentation Report, FWQA Dynamic Estuary Model. US Dept of the Interior, Federal Water Pollution Control Administration. July 1970.

[28] Sylvester, M. Application of Automatic Monitors for State Water Quality Surveillance. Dept. of Agricultural Engineering, Colorado State University, M.S. Thesis. August 1972. 143 p.

[29] Pennsylvania Department of Health, Region III. Report on the Beaver River. Harrisburg. 1963.

[30] US Dept. of Health, Education and Welfare. Report on Quality of Interstate Waters of the Mahoning River. Chicago. 1965.

[31] US Dept. of the Interior, Federal Water Pollution Control Administration, Ohio Basin Region. Benthic Biology of the Beaver River Basin—Ohio, Pennsylvania. Washington, DC. 1968.

SECTION XI

GLOSSARY

Abatement Objective - The system design goal in which the objective is to detect the occurence of water quality standards violations.

Basin Subset - The portion of a river basin that is under consideration in system design.

BOD - Biochemical Oxygen Demand.

Conservative Parameter - A water quality parameter that does not decay as a function of time, for example, dissolved solids. (See Appendix A.)

Critical Point - The point in a stream segment at which a water quality parameter reaches its worst value.

DO - Dissolved Oxygen.

Final Design - The stage of surveillance system design that deals with the total performance of the surveillance system in achieving its design goals.

Impact Nucleus - Same as Source Group.

"Macroscopic Concept" - The overview approach to system design that limits the spatial and temporal scales.

Means - A way of performing a function necessary to the production of water quality; an equipment, technology, device, person, or a combination of these.

NLT - Not less than.

Non-Conservative, Coupled Parameter - A water quality parameter for which the concentration in the stream is a function both of time and of the concentration of other parameters. An example is DO, which is coupled to BOD. (See Appendix A.)

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Non-Conservative, Non-Coupled Parameter - A water quality parameter for which the concentration in the stream is a function of time. BOD is an example. (See Appendix A.)

NTE - Not to exceed.

Preliminary Design - The stage of surveillance system design that deals solely with the relationship of the surveillance system to the natural system.

Reach - Same as Segment.

Segment - A length of stream in which the physical characteristics affecting water quality are assumed constant.

Source Group - A group of effluent outfalls considered as a single source for design purposes.

System Characteristics - The basic system attributes that must be described to permit analysis of cost-effectiveness.

System Duration - The time over which the water quality surveillance system will maintain a fixed configuration.

USGS - United States Geological Survey.

SECTION XII

APPENDICES

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APPENDIX A

SUMMARY OF RIBAM MATHEMATICAL FORMULATION

The version of RIBAM used in the development and demonstration of the system design methods is the original version developed for the Beaver River Basin Modeling Project [7]. One aspect of the application of RIBAM to a river basin is the assignment parameter code numbers to the water quality parameters selected for modeling. The assignment is specific to the application and may vary from basin to basin. The parameter code assignments for the Beaver River Basin and used in the demonstration case are listed in Table 33. The table also constitutes a list of the seventeen parameters modeled by RIBAM for the Beaver River Basin.

In addition to the seventeen water quality constituents, RIBAM models the following physical parameters:

1. Stream Flow in CFS
2. Stream Velocity in ft/sec
3. Time of Travel in days
4. Stream Depth in feet (computed only if dissolved oxygen is also computed).

The analytical approach used in RIBAM remains as defined in the DOSAG model [11]. The river basin is represented as a network consisting of four basic components. These four components are:

1. junctions—the confluence between two streams within the river basin being modeled
2. stretches—the length of river between junctions

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Table 33. WATER QUALITY PARAMETERS MODELED AND CODE NUMBER ASSIGNMENTS

Parameter Code Number	Parameter Name
1	Sulfates
2	Manganese
3	Iron
4	Total Nitrogen
5	Dissolved Solids
6	Lead
7	Chlorides
8	Phosphorous
9	Ammonia
10	Cyanides
11	Phenols
12	BOD
13	Coliforms
14	Nitrites
15	Nitrates
16	Chlorophyll A
17	Dissolved Oxygen

3. headwater stretches—the length of river from its headwater to its first junction with another stream

4. reaches—the subunits that comprise a stretch (either headwater or normal).

Reach boundaries are defined by any unique combination of the physical characteristics of the river basin, such as effluent sources, reaction rates or flow regimes. As a result of this definition, effluent sources are considered to enter the stream only at the upstream end, or head, of a reach.

To restrict the number of reaches, individual effluent sources are frequently grouped together. This grouping of individual sources is done only when the sources are in close proximity to each other. A more detailed discussion of the grouping procedure is presented in [3]. Sources are grouped together according to the type of the source. Three source types have been identified:

1. tributary streams
2. municipal wastewater sources
3. industrial process water sources.

These types are based on the functional characteristics of the sources. Tributary streams and municipal wastewater sources are considered to add to the net flow of the stream. Industrial sources are assumed to have no effect on the net flow of the stream, since industrial process water is most frequently withdrawn from the stream, then discharged back into the stream after use. Municipal wastewater sources have been separated from tributary streams to facilitate use of RIBAM in planning.

A fourth type of source has also been included in RIBAM, the unaccountable load. In the initial stages of model testing it is frequently found that large discrepancies exist between predicted and observed stream quality, possibly due to weaknesses in the data on source concentrations. To provide the capability to test agreement without adjusting any of the other three types of source data, the "inaccountable" load is introduced. It is so called, because the pollution loads associated with this source-type cannot be accounted for in the initially available data on known effluent sources. The unaccountable loads may be either positive or negative. They are treated as no-flow mass additions or withdrawals, not as concentrations. The necessity for inclusion of large unaccountable loads in any reach may be interpreted as an indication of very poor data for that reach.

The mathematical approach used in computation of the water quality parameters in the basin is a "piecewise continuous" approach, in which the parameter is assumed to behave according to a continuous differential equation throughout a reach. This approach may be used because the definition of a reach assumes that the important physical characteristics of the stream remain constant for the length of the reach. The model, thus, requires that the relevant physical characteristics of each reach of the stream be supplied as input data.

The mathematical models of stream quality are one-dimensional; they compute the concentration profile along the length of the stream. The concentrations are assumed to be uniform in depth and width.

The seventeen water quality parameters are grouped into three categories: 1) conservative, 2) non-conservative, non-coupled and 3) non-conservative, coupled. Each parameter within a given category obeys a general equation which is characteristic of that category.

In the conservative parameter equation, the concentration, C, of a water quality parameter is defined by:

$$\frac{dC}{dt} = 0 \tag{45}$$

the solution of which is:

$$C(t) = C^{\circ} \tag{46}$$

where C° is the concentration of the parameter at the head of the reach (i.e., at time equal to zero) and t is time.

The concentration at the head of the reach, C°, is determined by a mass balance equation. The mass balance equation describes the ratio of the total mass of the constituent entering the reach, both from the upstream reach and from all sources at the head of the reach, to the total flow in the reach. The mass balance equation is:

$$C^{\circ} = \frac{C_s Q_s + C_1 Q_1 + C_2 Q_2 + C_3^{*} Q_3^{*}}{Q_s + Q_1 + Q_2} \tag{47}$$

where Q_s = stream flow entering from the upstream reach
Q_1 = flow added by tributary streams
Q_2 = flow added by municipal wastewater sources
Q_3^{*} = flow passing through industrial sources
C_s = concentration of parameter entering from the upstream reach
C_1 = concentration of parameter in tributary streams
C_2 = concentration of parameter in municipal wastewater sources
C_3^{*} = net change in concentration of parameter between intake and discharge of industrial process water.

The asterisk is used to differentiate between the municipal/tributary-type sources, which add to total stream flow, and the industrial-type sources, which do not add to the total stream flow. The definitions above are carefully worded to reflect this difference.

The conservative parameters, or those parameters whose concentrations are assumed to be defined by the conservative parameter equation are:

Sulfates

Manganese

Iron

Total Nitrogen

Dissolved Solids

Lead Chlorides

In the non-conservative, non-coupled parameter equation, the concentration of a constituent is defined by:

$$\frac{dC}{dt} = -KC \qquad (48)$$

where K is the reaction rate of the constituent. The solution to the equation is:

$$C(t) = C^{\circ} e^{-Kt} \qquad (49)$$

In RIBAM, the following constituents are modeled by the non-conservative equation:

Phosphorous

Ammonia

Cyanides

Phenols

BOD

Coliforms

The non-conservative, coupled parameter equation has the characteristic of coupling the constituent in concern with one or more other constituents. The concentration of each of the following constituents is defined by a non-conservative, coupled equation:

Nitrites

Nitrates

Chlorophyll A

Dissolved Oxygen

While a general equation can be written for non-conservative, coupled parameters, because they are coupled to different constituents, each parameter has its own unique equation.

To simplify the presentation of these equations, a numerical subscript is assigned to each water quality parameter. The subscript assignments correspond to the code numbers used to represent each parameter in the computer programming.

The symbols used in the equations below are:

C_i = the concentration of parameter number i

K_i = the reaction rate of parameter number i

$K_{i,j}$ = the coupling coefficient between parameter number i and parameter number j

where i and j refer to the numbers in Table 33.

The nitrite parameter is assumed to be coupled to ammonia and is defined by the following equation:

$$\frac{dC_{14}}{dt} = -K_{14}C_{14} + K_{9,14}C_9 \qquad (50)$$

The solution to the previous equation for nitrites is:

$$C_{14}(t) = (C_{14}^{\circ} + A_{9,14})\, e^{-K_{14}t} - A_{9,14}\, e^{-K_9 t} \qquad (51)$$

where:

$$A_{9,14} = \frac{K_{9,14} C_9^\circ}{K_9 - K_{10}}$$

The nitrate parameter is assumed to be coupled to nitrites and is defined by the following equation:

$$\frac{dC_{15}}{dt} = -K_{15} C_{15} + K_{14,15} C_{14} \qquad (52)$$

The solution to the previous equation for nitrates is:

$$C_{15}(t) = (C_{15}^\circ + A_{9,15} + A_{14,15}) e^{-K_{15}t} - A_{14,15} e^{-K_{14}t} - A_{9,15} e^{-K_9 t} \qquad (53)$$

where:

$$A_{9,15} = \frac{-K_{14,15} A_{9,14}}{K_9 - K_{15}}$$

$$A_{14,15} = \frac{K_{14,15} (C_{14}^\circ + A_{9,14})}{K_{14} - K_{15}}$$

Chlorphyll A is assumed to be coupled to phosphorous and nitrates. Its concentration is defined by the equation:

$$\frac{dC_{16}}{dt} = -K_{16} C_{16} + K_{8,16} C_8 + K_{15,16} C_{15} \qquad (54)$$

The solution to the previous equation is:

$$C_{16}(t) = (C_{16}^{\circ} + A_{8,16} + A_{15,16} + A_{14,16} + A_{9,16})\,e^{-K_{16}t}$$

$$-A_{15,16}\,e^{-Kt} - A_{14,16}\,e^{-K_{15}t} - A_{14,16}\,e^{-K_{14}t} \qquad (55)$$

$$-A_{14,16}\,e^{-K_{14}t} - A_{9,16}\,e^{-K_{9}t} - A_{8,16}\,e^{-K_{8}t}$$

where:

$$A_{9,16} = \frac{-K_{15,16}A_{9,15}}{K_9 - K_{16}}$$

$$A_{14,16} = \frac{-K_{15,16}A_{14,15}}{K_{14} - K_{16}}$$

$$A_{15,16} = \frac{K_{15,16}(C_{15}^{\circ} + A_{14,15} + A_{9,15})}{K_{15} - K_{16}}$$

$$A_{7,16} = \frac{K_{7,16}C_7^{\circ}}{K_7 - K_{16}}$$

The dissolved oxygen deficit, D_{17}, is assumed to be coupled to iron, ammonia, BOD, nitrites, chlorophyll A and benthic oxygen demand. Its equation is:

$$\frac{dD_{17}}{dt} = -K_{17}D_{17} + A_3K_{3,17}C_3 + K_{9,17}C_9 + K_{14,17}C_{14}$$

$$+K_{12,17}C_{12} + K_{16,17}C_{16} + D_B \qquad (56)$$

where D_B = change in benthic oxygen

K_{17} = reaeration coefficient

A_3 = percent of total iron that is oxidizable

The solution to equation (12) is:

$$\begin{aligned} D_{17}(t) = (D_{17}^{\circ} &+ A_{3,17} + A_{9,17} + A_{14,17} + A_{15,17} \\ &+ A_{16,17} + A_{18,17} - b)\, e^{-K_{17}t} \\ &- A_{3,17}\, e^{-K_3 t} - A_{9,17}\, e^{-K_9 t} - A_{14,17}\, e^{-K_{14}} \\ &- A_{15,17}\, e^{-K_{15} t} - A_{12,17}\, d^{-K_{12} t} - A_{16,17}\, e^{-K_{16} t} \\ &- A_{8,17}\, e^{-K_8 t} + b \end{aligned} \tag{57}$$

where

$$A_{3,17} = \frac{A_3 K_{3,17} C_3^{\circ}}{K_3 - K_{17}}$$

$$A_{12,17} = \frac{K_{12,17} C_{12}^{\circ}}{K_{12} - K_{14}}$$

$$A_{16,17} = \frac{K_{16,17} (C_{16}^{\circ} + A_{15,16} + A_{14,16} + A_{9,16})}{K_{16} - K_{17}}$$

$$A_{15,17} = \frac{-K_{16,17} A_{15,16}}{K_{15} - K_{17}}$$

$$A_{14,17} = \frac{K_{14,17}(C^{\circ}_{14} + A_{9,14}) - K_{16,17}A_{14,16}}{K_{14} - K_{17}}$$

$$A_{9,17} = \frac{K_{9,17}C^{\circ}_{9} - A_{9,14}K_{14,17} - A_{9,16}K_{9,16}K_{16,17}}{K_{9} - K_{17}}$$

$$A_{8,17} = \frac{-K_{16,17}A_{8,16}}{K_{8} - K_{17}}$$

$$b = D_B/K_{17}$$

Dissolved oxygen concentration is determined by taking the difference between saturated dissolved oxygen (C_{SAT}) and the dissolved oxygen deficit.

$$C_{17}(t) = C_{sat} - D_{17}(t) \qquad (58)$$

The saturation dissolved oxygen is estimated with the following equation:

$$C_{SAT} = (14.62 - (0.3898{*}T) + (0.006060{*}T^2) - (0.00005897{*}T^3)){*}((1. - (0.00000697{*}E))^{5.67}) \qquad (59)$$

where T = reach temperature (°C)

E = mean basin elevation (feet above sea level)

The reaeration coefficient, K_{17}, may either be assumed to remain constant for all flow regimes, or it may be computed by one of two methods.

The first method assumes:

$$K_{17} = \frac{A*V^B}{D^C} \quad (60)$$

where V = the stream velocity

D = the stream depth

and A, B, and C are constants that must be obtained for each reach by statistical methods from observational data. The stream velocity may, in turn, be estimated using the equation

$$V = a*Q^b \quad (61)$$

where Q = the stream flow

a, b = constants estimated by statistical methods from observational data for each reach

The depth, D, may either be provided by the user from hydrographic data or it may be estimated by the equation:

$$D = c*Q^d \quad (62)$$

where Q = the stream flow

c, d = constants estimated by statistical methods from observational data for each reach

The second method for estimation of the reaeration coefficient assumes that:

$$K_{17} = \alpha *Q^{\beta} \quad (63)$$

where Q = stream flow

and the two constants, α and β, are estimated statistically for each reach of the basin.

The value of the reaeration coefficient, no matter which method is used, is determined for a temperature of 20°C. The value is adjusted for temperature dependency according to the equation:

$$K_{17}(T) = K_{17}(20°C)*1.0159^{(T-20)} \tag{64}$$

where T = the reach temperature (°C).

Another physical process that affects the dissolved oxygen deficit is the turbulent mixing as the water flows over a dam. The change in the dissolved oxygen deficit, D, as the stream flows over a dam is computed according to the following equation:

$$D_D = \frac{D_u}{1.0 + 0.11*(1.0 + 0.046T)h} \tag{65}$$

where D_D = dissolved oxygen deficit below dam

D_u = dissolved oxygen deficit above dam

T = temperature of reach where dam is located (°C)

h = height of dam (feet)

The value of each parameter is computed for any point in a reach by evaluating the appropriate equation for the time of travel from the head of the reach to the point. Time of travel is computed by the usual time-rate-distance equation:

$$t = \frac{x}{V} \tag{66}$$

where x = the distance downstream from the head of the reach.

The major restriction of the mathematical models is in the consideration of deep impoundments. The mathematical models are so-called one-dimensional models and are restricted to cases in which the concentration profiles along the depth and width dimensions can be considered uniform. Clearly, deep impoundments such as deep reservoirs violate these conditions because of the vertical stratification in such reservoirs. RIBAM may not be used to simulate water quality in a deep impoundment. It may, however, be used to simulate a basin containing impoundments of sufficiently shallow depth that they are essentially one-dimensional. In the latter case, the effect of dam spillways on reaeration is included in the model.

Non-conservative, coupled parameters can be simulated only under the restriction that the reaction rates of coupled parameters are not equal. The restriction are due to the nature of the solutions of the particular equations describing each non-conservative, coupled parameter. A list of the restrictions is presented in Table 34.

Table 34. LIMITATIONS ON REACTION RATES OF COUPLED PARAMETERS

Non-conservative, Coupled Parameter	Reaction Rates that Cannot be Equal
Nitrites	$K_9 \neq K_{14}$
Nitrates	$K_9 \neq K_{15}$, $K_{14} \neq K_{15}$
Chlorophyll A	$K_9 \neq K_{16}$, $K_{14} \neq K_{16}$, $K_8 \neq K_{16}$
Dissolved Oxygen	$K_3 \neq K_{17}$, $K_{16} \neq K_{17}$, $K_{14} \neq K_{17}$, $K_{12} \neq K_{17}$, $K_{15} \neq K_{17}$, $K_9 \neq K_{17}$

APPENDIX B

DEVELOPMENT OF TOTAL SYSTEM EFFECTIVENESS

For the design of river basin water quality surveillance systems, the total system effectiveness is defined as the ratio of the expected number of detections of violations to the expected number of violations. More precisely, E_{sys} is defined as:

$$E_{sys} = \frac{\text{Expected number of independent violations to be detected by the system over the system duration}}{\text{Expected number of independent violations in the basin over the system duration}} \tag{67}$$

The conceptual bases for the definition are discussed in Section VI.

Implicit in the definition are two assumptions. First, all violations are equally weighted, regardless of which water quality parameter is causing the violation. Second, all violations are equally weighted, regardless of the location of the violation. These assumptions are justified by the analysis of stream water quality standards presented in [3]. The stream standards are considered to be society's judgment of the importance of each parameter in each reach of the basin. The quantitative value of the standard for each parameter in each reach constitutes sufficient weighting of the design analysis to reflect this judgment.

In order to develop a mathematical formulation for the definition of total system effectiveness, consider a simple river basin. It consists of one river with no tributaries. To aid in the mathematical formulation, the segments are numbered in sequence beginning with the headwaters. Similarly, each monitoring station is numbered in another sequence beginning with the most upstream station. For each parameter, there is only one monitoring station per reach.

The denominator of equation (67) can readily be expressed by counting the expected number of independent violations that come into existence in each segment. The resulting mathematical formulation is adequately described in Section VI. It is

$$\sum_{j=1}^{J} \sum_{i=1}^{I} n_v^{**}(i, j) \tag{68}$$

where i = the segment index number

j = the parameter index number

I = the maximum i

J = the maximum j

$n_v^{**}(i, j)$ = the expected number of type 2 violations of parameter j in segment i.

An expression for the numerator of equation (67) is much more complex. For each violation of parameter j that occurs in the k^{th} monitored segment, i_k, the numerator must include:

1. the possibility that the violation may or may not be detected in segment i_k
2. the spatial extent of the violation, and
3. the possibility that the violation may or may not be detected at any other monitored segment in which it exists.

By ennumerating these conditions from the headwaters to the month, it is possible to limit consideration of each of these factors to the portion of the basin upstream of each segment. The resulting expression is

$$\sum_{j=1}^{J} \left\{ \sum_{k=1}^{K} P_{D|V}(i_k, j) \left[\sum_{\ell=1}^{k} N(i_k, j; i_{\ell-1}, i_\ell) \cdot \left(\prod_{m=\ell}^{k-1} \left[1 - P_{D|V}(i_m, j)\right] \right) \right] \right\} \tag{69}$$

where j = the parameter index number

k = the monitoring station index number

i_k = the segment containing the k^{th} monitoring station

ℓ, m = dummy indices identical to k

$P_{D|V}(i_k, j)$ = the probability of detecting each violation of parameter j that occurs in segment i_k

$N(i_k, j; i_{\ell-1}, i_\ell)$ = the expected number of violations of parameter j that occur in segment i_k and that begin upstream of or in segment i_ℓ, but downstream of segment $i_{\ell-1}$.

The term "begin" above refers to the upstream boundary of the violation, as described in Section VI.

To understand expression (69) fully, a term-by-term examination of the expression is necessary. If only one parameter is considered, the equation can be rewritten in simplified form:

$$\sum_{k=1}^{K} P_{D|V}(i_k) \left\{ \sum_{\ell=1}^{k} N(i_k; i_{\ell-1}, i_\ell) \left[\prod_{m=\ell}^{k-1} \left(1 - P_{D|V}(i_m)\right) \right] \right\} \tag{70}$$

The term:

$$\sum_{\ell=1}^{k} N(i_k; i_{\ell-1}, i_\ell) \tag{71}$$

is the total expected number of violations that occur in monitored segment i_k. Because of the segment numbering scheme, they must begin in the interval $[1 \le i \le i_k]$. If there is an upstream monitoring station (i_{k-1}), those violations that begin upstream of i_{k-1} may be detected at i_{k-1}. Similarly, if there are two monitoring stations upstream of i_k $(i_{k-1}$ and $i_{k-2})$, violations that begin upstream of i_{k-2} may be caught at either i_{k-2} or i_{k-1}. Since the objective is to count as detections in i_k only those violations not detected elsewhere, the expected number of undetected violations in i_k that begin in the interval (i_{k-2}, i_{k-1}) is:

$$N(i_k; i_{k-2}, i_{k-1}) \left|1 - P_{D|V}(i_{k-1})\right| \tag{72}$$

Similarly, the expected number of undetected violations in i_k that begin upstream of i_{k-2} is:

$$N(i_k; i_{k-3}, i_{k-2}) \left|1 - P_{D|V}(i_{k-2})\right| \left|1 - P_{D|V}(i_{k-1})\right| \tag{73}$$

Thus:

$$\sum_{\ell=1}^{k} N(i_k; i_{\ell-1}, i_\ell) \left[\prod_{m=\ell}^{k-1} \left(1 - P_{D|V}(i_m)\right) \right] \tag{74}$$

is the expected number of previously undetected violations that occur in segment i_k. Of those, the expected number that are detected in i_k is:

$$P_{D|V}(i_k) \sum_{\ell=1}^{k} N(i_k; i_{\ell-1}, i_\ell) \left[\prod_{m=\ell}^{k-1} \left(1 - P_{D|V}(i_m)\right) \right] \tag{75}$$

Finally, the total number of independent violations of the parameter under consideration throughout the basin is the sum over k given by expression (70).

Implicit in this development is the assumption that $P_{D|V}$ is independent of the violation, that is, $P_{D|V}$ is the average probability of detection. This probability could be defined as the effectiveness of the system element $E(i_k, j)$.

The estimation of expression (69) in the context of system design is a difficult task and simplification is desirable. The desired simplification can be achieved if either of two conditions apply:

1. $N(i_k, j; i_{\ell-1}, i_\ell)$ small for $\ell < k - 1$ or
2. $P_{D|V}(i_m, j)$ approaches 1, that is the individual elemental effectiveness, $E(i_k, j)$, is high.

Under either of these circumstances, expression (69) reduces to:

$$\sum_{j=1}^{J} \sum_{k=1}^{K} P_{D|V}(i_k, j)\, N(i_k, j; i_{k-1}, i_k) \qquad (76)$$

Expression (76) is the form of the numerator for equation (14) used in equation (15), where:

$$n_d^*(i_k, j) = P_{D|V}(i_k, j)\, N(i_k, j; i_{k-1}, i_k) \qquad (77)$$

This form (expression (77)) can be compared with equation (16) where:

$$n_v^*(i_k, j) = N(i_k, j; i_{k-1}, i_k) \qquad (78)$$

Thus, the approximate form of the total system effectiveness is (equation (15)):

$$E_{sys} = \frac{\sum_{k=1}^{K} \sum_{j=1}^{J} n_d^*(i_k, j)}{\sum_{i=1}^{I} \sum_{j=1}^{J} n_v^{**}(i, j)} \qquad (79)$$

The approximation holds for sparse monitoring networks in which condition (1) is most likely to apply. It is clear that assumption of such conditions for the demonstration case described in Section VIII is valid and it is anticipated that the assumption is generally valid. However, the system designer must be aware of the assumption in the evaluation of his design analysis.

APPENDIX C

DEVELOPMENT OF FULL FORM FOR ESTIMATION OF CAPABILITY

As indicated in Section VI, a more elegant mathematical approach to the estimation of capability than that used by the design method is available. It is based on a direct application of the equation for expected number of detections developed in [3], rather than the indirect approach described in Section VI. Unfortunately, the estimation of some of the independent variables from the available data presents difficulties. The more elegant approach is presented here for completeness and for guidance, should a system designer prefer to implement a less approximate method for computing capability.

As developed in [3], the expected number of violations sampled, n_s, can be computed with the equation:

$$n_s = \frac{T_0 T_1}{\Delta\left(T_0^2 - T_1^2\right)} \left[\exp\left(\frac{-\Delta}{T_0}\right) - \exp\left(\frac{-\Delta}{T_1}\right)\right] \qquad (80)$$

where Δ = the sampling interval

T_1 = the expected duration of a violation

T_0 = the expected interval between violations.

All of the factors affecting system capability can be directly incorporated in equation (80) by suitably defining the independent variables: Δ, T_1 and T_0. The effect of routine maintenance can be included in the same manner as in Section VI, through use of an effective sampling interval, Δ_e. The effects of sampling location and random analysis errors can be incorporated through computation of T_1's and T_0's corresponding to the violation process as viewed by the surveillance system. These new variables are characteristic of the violations liable to be detected and are designated: T_1^d and T_0^d.

Thus, given that the system has survived and is available, the expected number of detections can be estimated as:

$$n_d^*(x, \Delta_e, \bar{\epsilon}, \sigma_\epsilon \mid \underline{a}, \underline{s})$$

$$= \frac{T_0^{\ d} T_1^{\ d}}{\Delta_e \left[\left(T_0^{\ d}\right)^2 - \left(T_1^{\ d}\right)^2\right]} \left[\exp\left(\frac{-\Delta_e}{T_0^{\ d}}\right) - \exp\left(\frac{-\Delta_e}{T_1^{\ d}}\right)\right] \tag{81}$$

The development of an estimate for Δ_e is described in Appendix D. The remainder of this appendix is directed at the problematical $T_0^{\ d}$ and $T_1^{\ d}$ estimates.

In order to develop the approach to estimating $T_1^{\ d}$ and $T_0^{\ d}$, consider the process under surveillance, as viewed by whatever device or person makes the no-violation-violation decision. It consists of the true value of concentration at the location of sampling, C(x), and a random observational error, $\underline{\epsilon}$. Thus, the observed value, C'(x), is:

$$C'(x) = C(x) + \underline{\epsilon} \tag{82}$$

As developed in Section VI, a violation is considered to have occurred whenever the observed value exceeds the threshold value, C_T. That is:

$$C(x) > C_T - \underline{\epsilon} \rightarrow \text{violation} \tag{83}$$

Inequality (83) implies that $T_1^{\ d}$ and $T_0^{\ d}$ are found in the same way as T_1 and T_0 in [3], except that the location is x, rather than x_m (the preferred location) and the effective threshold is $(C_T - \underline{\epsilon})$, rather than C_T.

It is clear that $(C_T - \underline{\epsilon})$ is a random variable, since the random error $\underline{\epsilon}$ is never known precisely. An assumption of this method, however, is that the mean, $\bar{\epsilon}$, and standard duration, σ_ϵ, are known reasonably well. If $p(\underline{\epsilon} \mid \bar{\epsilon}, \sigma_\epsilon)$ is the probability density function of $\underline{\epsilon}$, given $\bar{\epsilon}$ and σ_ϵ, then the expected time durations, T_1^d and T_0^d, in equation (81) can be replaced by values averaged over $\underline{\epsilon}$. That is, replace T_1^d and T_0^d by $\bar{T}_1^d$ and $\bar{T}_0^d$, respectively, where:

$$\bar{T}_i^d = \bar{T}_i(x, \bar{\epsilon}, \sigma_\epsilon) = \int_{-\infty}^{\infty} T_i(x, \underline{\epsilon})\, p(\underline{\epsilon} \,|\, \bar{\epsilon}, \sigma_\epsilon)\, d\underline{\epsilon} \tag{84}$$

for $i = 0, 1$.

Direct computation of the integral in equation (84) requires a knowledge of $p(\underline{\epsilon} \,|\, \bar{\epsilon}, \sigma_\epsilon)$ and of the functional relationship between T_i and $\underline{\epsilon}$. For purposes of surveillance system design, it is sufficient to assume that the errors behave according to a gaussian probability density function. The other requirement can be satisfied by adapting the approach used for estimation of the T_i developed in [3]. As discussed in Section VI, the threshold concentration is translated into a threshold flow using the mathematical models descriptive of the basin. Using the threshold flows, data on the duration of violations and the interval between can be accumulated from USGS flow records and the average values computed. In the present case, the concentration threshold is a random variable, so the flow threshold is also random:

$$\underline{Q}'_T = Q_T - \underline{\delta} \tag{85}$$

in which $\underline{\delta}$ is the equivalent random stream flow threshold error. If $\underline{\epsilon}$ is sufficiently small relative to C_T, then it is possible to relate $\bar{\epsilon}$ and σ_ϵ to the mean and standard deviation of $\underline{\delta}$ ($\bar{\delta}$ and σ_δ). Under the assumed condition, the nonlinearities in the relationship between C and Q can be ignored. This leads to a gaussian $\underline{\delta}$ with:

$$\bar{\delta} = Q_T - f(C_T - \bar{\epsilon}) \tag{86}$$

$$\sigma_\delta = Q_T - f(C_T - \sigma_\epsilon) \tag{87}$$

where the functional form, f(-), is derived from the relationship between C and Q.

Thus, the integral in equation (84) can be replaced by:

$$\bar{T}_i^{\,d} = \bar{T}_i^{\,d}(x, \bar{\delta}, \sigma_\delta) = \int_{-\infty}^{\infty} T_i(x, \underset{\sim}{Q}_T') \, N(\underset{\sim}{Q}_T' \mid \bar{\delta}, \sigma_\delta) \, d\underset{\sim}{Q}_T' \qquad (88)$$

where $\underset{\sim}{Q}_T'$ is the random threshold flow. The relationship between T_i and $\underset{\sim}{Q}_T'$ at locations x can be developed empirically from the USGS data by examining the flow record for a number of Q_T's and fitting an appropriate curve. It is then necessary to perform a numerical integration to evaluate equation (88). An alternative is to assume an integrable form for $T_i^{\,d}(x, \underset{\sim}{Q}_T)$, such as an exponential, and evaluate the equation analytically. If, for example, it is assumed that:

$$T_i^{\,d}(x, \underset{\sim}{Q}_T) = a_i \exp\,[b_i \underset{\sim}{Q}_T] \qquad (89)$$

then

$$\bar{T}_i^{\,d} = a_i \exp\left[b_i(Q_T - \bar{\delta}) + \frac{b_i^2 \sigma_\delta}{2}\right] \qquad (90)$$

where Q_T is the flow threshold corresponding to C_T.

Neither of these two approaches is particularly satisfactory in the present context. Numerical integration of general equations presents difficulties that far outway its usefulness for system design. Yet, it is difficult to find an integrable form for $T_i^{\,d}(x, \underset{\sim}{Q}_T)$ that is sufficiently descriptive of the actual data over the broad range of possible values. For example, the exponential cited above is a very poor approximation for low flow conditions.

It is for these reasons that the more pragmatic formulation described in Section VI is preferred over the formulation presented in this appendix.

APPENDIX D

EFFECTIVE SAMPLING INTERVAL

In the development of the water quality surveillance system design methodology, it is assumed that the system is a sampled system. That assumption appears valid for a large number of expected cases, ranging from the fully-manned surveillance system taking monthly or weekly samples, to the fully automated system transmitting samples to a central station on an hourly schedule.

As is done in [3], sampled data systems taking essentially instantaneous observations can be characterized by the interval between samples, Δ. It is assumed in [3] that the sampling scheme is a periodic function, with any random error in the timing of the sample considered negligibly small in comparison with the period. That assumption seems to characterize the majority of routine sampling schedules that may be expected.

The measure of sampling effectiveness developed in [3] is based on an assumed regular sampling scheme, with sampling interval Δ.

However, it can be seen from an examination of the development of the measure that it holds, at least approximately, for a random sampling process with an effective sampling interval equal to the mean sampling interval, $\Delta_e = \overline{\Delta}$. It is only approximately true, since the artifice by which multiple detections are eliminated no longer holds exactly. If a random sample replaces a periodic sample, some violations that would otherwise be detected once are detected more than once and others not at all. On the average the total number of detections is the same, although they are no longer all independent detections. The approximation improves as the variance of the sampling interval approaches 0.

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In the present development, the effect of routine maintenance must be incorporated in the computation of system effectiveness.

As shown in Figure 66, the routine maintenance process modulates the periodic sampling process. There are two cases possible. In the first, the next sample following the maintenance downtime is taken as if the sampling sequence had never been interrupted. In the second, the next sample immediately follows the return to service and the sampling sequence is reset to that time. Clearly, the two cases merge when $T_u + T_d = n\Delta$, any integer multiple of Δ.

The resulting sampling process can be thought of as an approximately random sample, for system design purposes. It has a mean sample interval and a well defined variance, when a long enough time period is considered. For typical routine maintenance in which $T_u >> T_d$, the variance is small and the measure of sampling effectiveness developed in [3] is approximately true.

The computation of that measure then depends on an estimate of the effective sampling interval under routine maintenance conditons. Examination of Figure 66 leads to the following formula for estimating Δ_e in each case.

The expected number of samples that are taken during the operating period (N_u) is the truncated (integer) value of the quotient:

$$N_u = \text{Int}\left(\frac{T_u}{\Delta}\right) \tag{91}$$

Similarly, the expected number of samples that would have been taken during the maintenance period (N_d) is:

$$N_d = \text{Int}\left(\frac{T_u}{\Delta}\right) \tag{92}$$

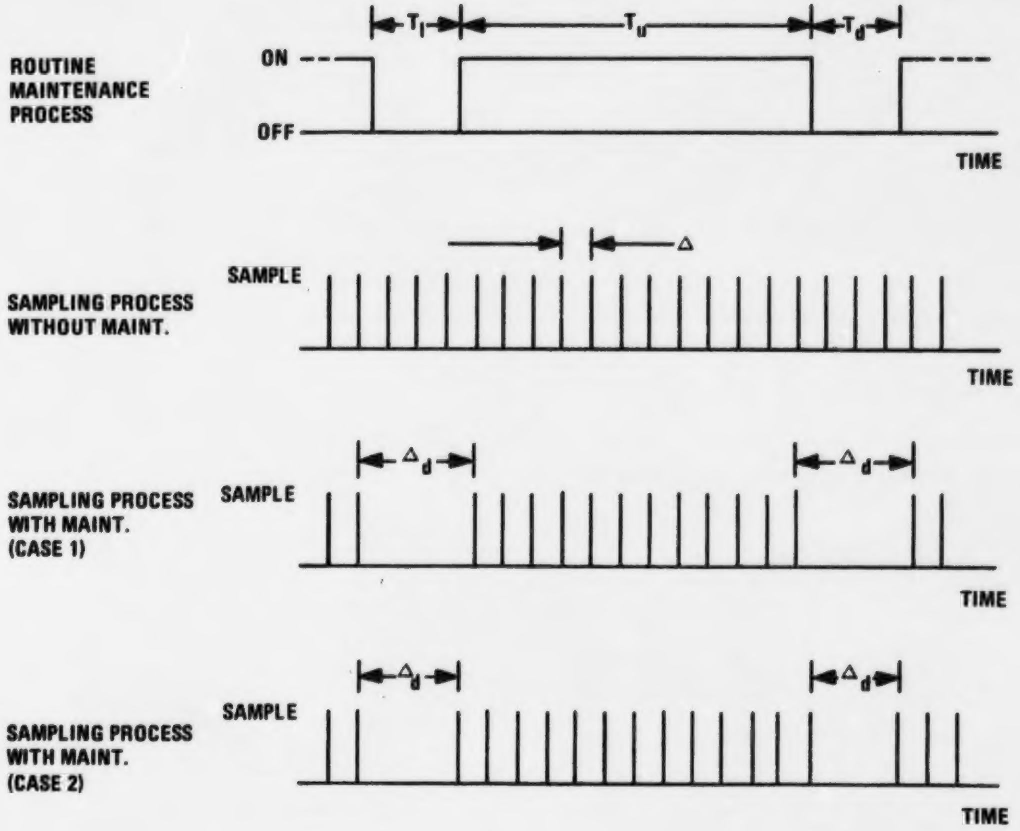

ROUTINE MAINTENANCE PROCESS
ON
OFF
T_l
T_u
T_d
TIME
SAMPLING PROCESS WITHOUT MAINT.
SAMPLE
Δ
TIME
SAMPLING PROCESS WITH MAINT. (CASE 1)
SAMPLE
Δ_d
Δ_d
TIME
SAMPLING PROCESS WITH MAINT. (CASE 2)
SAMPLE
Δ_d
Δ_d
TIME

Figure 66. Effect of Routine Maintenance on Periodic Sampling

The new sampling interval during the maintenance period (Δ_d) is, for case 1:

$$\Delta_d = (N_d + 1)\Delta \tag{93}$$

The sample interval during the operating period is still Δ, the effective, or average, sampling interval (Δ_e) for case 1 is:

$$\Delta_e = \frac{1}{N_u + 1}(\Delta_d + N_u\Delta) \tag{94}$$

$$= \frac{(N_d + N_u + 1)\Delta}{N_u + 1}$$

For case 2, the Δ_d is computed according to the equation:

$$\Delta_d = N_d\Delta + (T_u - N_u\Delta) \tag{95}$$

giving the effective sampling interval of

$$\Delta_e = \frac{1}{N_u + 1}(\Delta_d + N_u\Delta) \tag{96}$$

$$= \frac{N_d\Delta + (T_u - N_u\Delta) + N_u\Delta}{N_u + 1}$$

$$= \frac{N_d\Delta + T_u}{N_u + 1}$$

It is assumed that the system designer will ordinarily plan maintenance to fall between sample times when $T_d < \Delta$. In that case, N_d goes to zero and $\Delta_e = \Delta$.

APPENDIX E

DEVELOPMENT OF COMPUTERIZED SYSTEM DESIGN METHODS

The development of the computational procedures for the design of water quality surveillance systems is based on the theoretical developments of Section VI and [3], and on the total design method outlined in Section VII. For the most part, it requires straight forward computer programming of the mathematical formulation. In some cases, it requires the use of approximations, the adaptation of existing programming and the development of special mechanisms for handling aspects of the problem.

The objective of this appendix is to provide an understanding of the nature and content of the design programs presented in detail in Appendix F. Toward this end, specific highlights are described in detail. These highlights are selected for discussion because they do not necessarily derive directly from the theoretical base of the design method.

SELECTION OF BASIN MODEL

As anticipated in Section IV, the necessary description of the natural system used in the evaluation of surveillance system design is provided by a computerized mathematical river basin planning model. The model used is the RIver BAsin Model (RIBAM) developed by Raytheon OES for the Environmental Protection Agency [7]. Selection of RIBAM for use in this project is based on more than the coincidence of authorship, although that is a factor in the choice.

The essential criteria in the choice of a river basin model for use in surveillance system design are:

1. The computerized model must be of the same type as the manual model used in the initial development of the design methods (i.e., steady-state,

one-dimensional, capable of handling conservative, non-conservative non-coupled, and non-conservative coupled parameters.

2. That it be available for general application through the EPA when the design methods were published.

3. That it be available to the design methods project at the required point in time.

At the time the present project was begun a number of EPA water quality models existed. They included the DOSAG [11], QUAL-I [21,22], RECEIV portion of the Storm Water Management Model [23], RESERVOIR [24,25], PLUME [26], and DEM [27] models.

In addition, each of the foregoing models has been undergoing adaptation and expansion for use in the various basins being modeled under EPA's River Basin Planning Models Program, of which the Beaver River Basin Model Project is only one segment [7]. These changes include, in general, expansion to include additional parameters and modification to incorporate more complex coupling of non-conservative parameters. As discussed in Section IV, the RIBAM model resulted from such modification and adaptation of the DOSAG model, for use by Raytheon OES in the Beaver River Project. Other such improved versions have not been available to the design methods project, since the work has been in process by other EPA contractors.

Choice of RIBAM is based on an elimination process. PLUME was not directly relevant to the processes to be modeled, since it models only the near-field of an outfall. RESERVOIR and DEM are two-dimensional models, not one-dimensional. RECEIV and QUAL-I are dynamic models, not steady state. RIBAM is selected over DOSAG, (also a one-dimensional, steady-state model) because it is more general in the parameter coverage and the mathematical treatment.

As it is used in the design methods programs, RIBAM is computationally identical to the stand-alone version used for basin planning. The main program portion of RIBAM has been converted to subroutine form and adapted to the design procedure. All printed output from the RIBAM computations has been eliminated, since it is assumed that the user will have calibrated the model using the stand-alone version, as described in the Beaver River Project Documentation Report [7]. The stand-alone version requires the preparation of two sets of input data cards, the Program Control Deck and the Standard Data Deck. As used in the design methods program, the Standard Data Deck is retained intact. The necessary information from the Program Control Deck has been combined with other information on the "CONTROL" card in the design methods data deck.

PROGRAM DETAILS

With the overall understanding of the programs provided by Section VII, it is possible to highlight the more important details of the programming. The objective of the following paragraphs is to describe the implementation of the concepts developed in Section VII and [3].

Estimation of n_s^* and n_v^{**}

As detailed in Section VI, the computation of n_s^* and n_v^{**} depend on the estimation of the expected durations T_0^*, T_1^*, T_0^{**} and T_1^{**}.

The estimation approach used in the development of the design analysis programs is the same as that used in [3].

It is assumed that, at the macroscopic scales under consideration, the statistical variability of the water quality is due primarily to variability of the stream flow. The estimation approach, thus, calls for translation of the water quality threshold specified by the stream standards into thresholds on stream flow. It is also assumed that the stream flow in the basin is statistically stationary over the period of the USGS gaging records for the basin. Comparison of the flow thresholds with the USGS data then allows the accumulation of statistics on T_0's and T_1's.

Thus, the computation of n_s* and n_v** for each system element may be separated into three steps: 1) the computation of a threshold flow, Q_T, for each system element, 2) the analysis of the USGS data for the T_0's and T_1's, and 3) use of the T_0's and T_1's to compute the n_s* and n_v** values.

Estimation of Threshold Flows—

The approach used to compute the threshold flows in Subroutine QTCAL is an indirect, estimation approach. In general, it is not possible to solve explicitly the equations relating concentration of a water quality parameter to physical factors in the stream such as stream flow. Thus, one cannot straightforwardly solve for the threshold flow Q_T, by substitution of the water quality standards threshold, C_T, into the concentration equations.

Instead, the concentration of the water quality parameter is computed for five values of stream flow. The five values are computed by QTCAL by applying scaling factors to the standard flow values specified in the RIBAM Standard Data Deck. The selection of the scaling factors is done once for the entire basin and provided as input data to Subroutine RPC. In selecting the scaling factor, the designer will attempt to assure that the range of flows is sufficient to cause the computed concentrations to bracket the C_T's for most parameters. The designer must also be careful not to specify a scaling factor that will "dry up" the river, that is, not provide sufficient flow to maintain the expected river uses specified in the RIBAM Standard Data Deck.

Using the five computed points, a C versus Q curve is fit by the ICSSMU subroutine. That subroutine performs a cubic spline curve fit. That is, it computes the coefficients of five cubic equations for curves joining the points, such that the weighted average difference in slopes at the points is a minimum (see Figure 67).

Mathematically, this is approximately equivalent to the curve fit that would be achieved by a draftsman using a supple wooden or metal strip - a spline - to draw a curve through the points. The cubic spline approach was selected because it forces the resulting curves to go through the points being fitted. This is in contrast to other types of curve fitting, such as least squares, in which the resulting curve may or may not pass through the points.

A value for Q_T may then be computed by interpolation, using the cubic equation appropriate to the range of values containing C_T. Clearly, this process must be

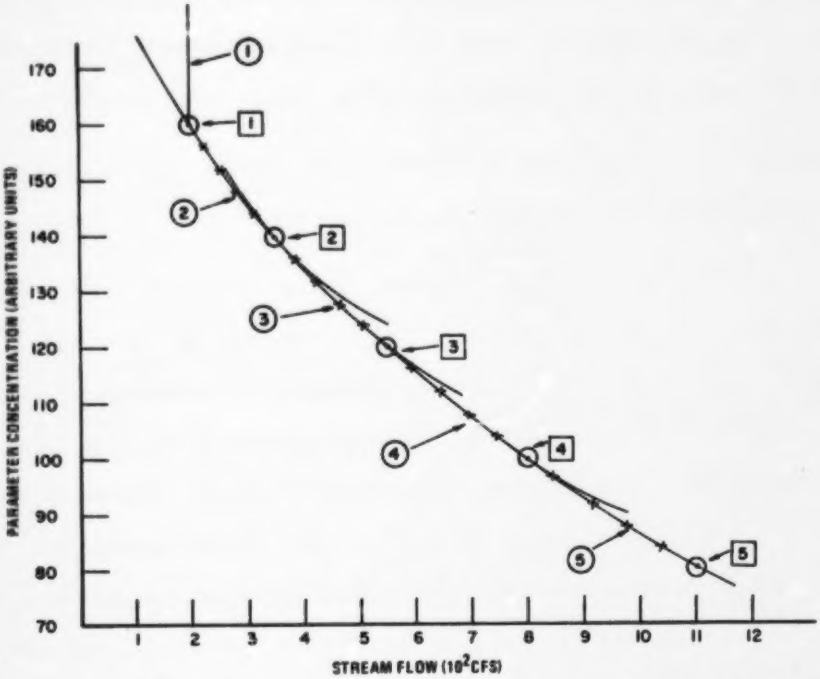


Figure 67. Concentration vs Flow Curve Fitting (Boxed Numbers Indicate Data Points and Circled Numbers Indicated Associated Curves)

repeated for each reach of the basin for each parameter included in the system design.

Estimation of the Expected Durations—

Using the Q_T's, the USGS gaging station records for the basin may then be examined for periods falling above and below the threshold. While this is a relatively straightforward process, two factors have been carefully included in Subroutine EXPDUR.

The first is the relationship between the basin reaches and the network of USGS gaging stations. Typically, there are many fewer stations than there are reaches. In the preparation of the RIBAM Standard Data Deck, the system designer will have selected the gaging station most representative of each reach and determined the relationship between the flow at the station and the flow at the reach. The reach-station relationship is applied to the Q_T's, which are then compared directly with the gaging station data.

The second is the identification of violations that fit into the "single-star" or "double-star" categories, as defined in Section VI.

For the case of the "double-star" violation, the key property is the continuity of the violation into the next upstream reach of the stream. For non-coupled parameters, a reach is said to contain a "double-star" violation if the head of the reach is in violation state but the end of the upstream reach is not in violation (see Figure 68). For the case of coupled parameters, the condition is satisfied if: 1) a violation exists at the worst point in the reach, 2) a violation exists at the best point in the reach upstream of the worst point, and 3) if a violation does not exist at the best point in the next upstream reach that is downstream of the worst point in the upstream reach (see Figure 69). If the reach is a headwater reach, existence of a violation qualifies as a "double-star"

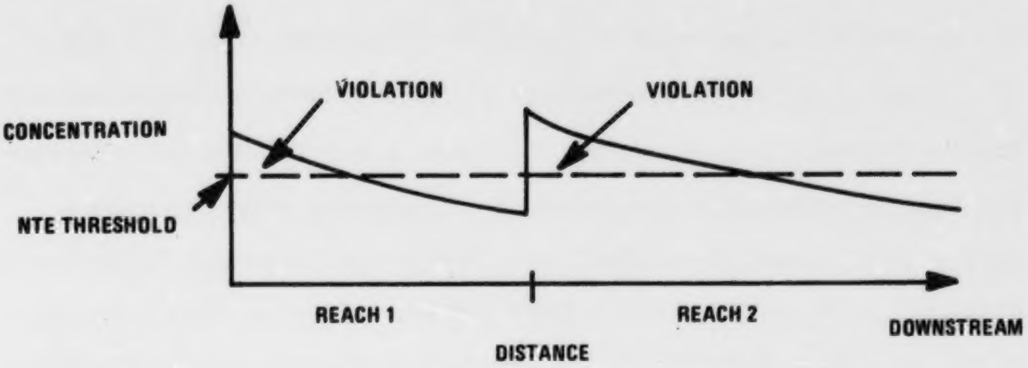

VIOLATION
VIOLATION
CONCENTRATION
NTE THRESHOLD
REACH 1
REACH 2
DOWNSTREAM
DISTANCE

Figure 68. "Double Star" Violation of a Non-coupled Parameter

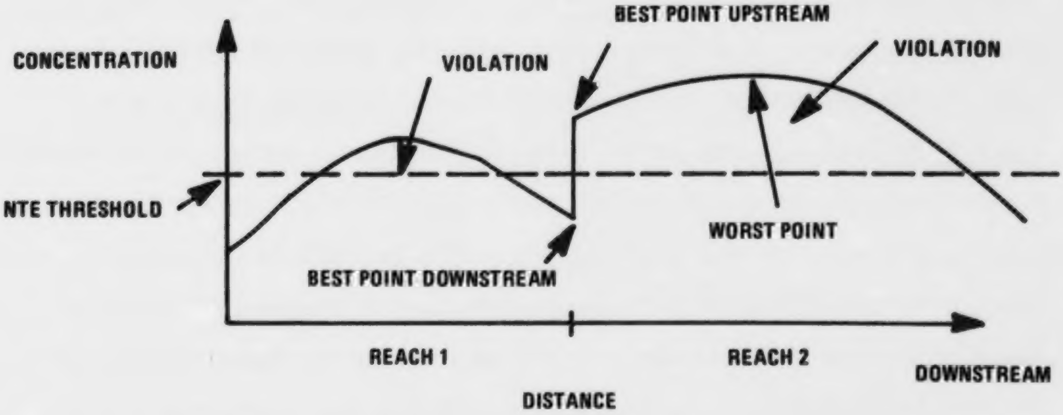

BEST POINT UPSTREAM
CONCENTRATION
VIOLATION
VIOLATION
NTE THRESHOLD
WORST POINT
BEST POINT DOWNSTREAM
REACH 1
REACH 2
DOWNSTREAM
DISTANCE

Figure 69. "Double Star" Violation of a Coupled Parameter

violation. If the reach is below a junction, the conditions must hold in both upstream segments to satisfy the definitions of a "double-star" violation.

For the case of a "single-star" violation, the key property is the continuity of the violation from the reach containing the proposed station to the next upstream reach containing a proposed station. In this case, any violation that is continuous from the reach under consideration to any upstream reach containing a station fails to satisfy the conditions on a "single-star" violation. In the case of stations above and below one or more junctions, detection of the violation on any one of the upstream branches constitutes a failure to satisfy the conditions. For coupled parameters, the existence of a violation must be tested at best and worst points of each upstream reach to establish continuity of the violation (see Figure 70).

Clearly, the computation of the T_0* and T_1* requires continual searching of upstream segments. Because the reach numbering scheme is entirely arbitrary when the RIBAM Standard Data Deck is prepared, the search would require continual referencing of the arrays describing the basin topology. In preference to such time-consuming referencing, Subroutine EXPDUR performs the topology mapping only once. It sets up an array of masks that indicate the upstream reaches that must be checked for the identification of "single-star" violation. The subroutine first checks each reach in the basin for its violation state and then overlays the masks to determine those reaches with "single-star" violations. It should be noted that use of this masking technique limits the number of stream reaches that may be modelled to the number of bits per word of memory in the computer used. The user may remove this limitation for any specific machine by implementing a multi-word masking approach. The original programming was performed on the 60-bit/word CDC 6700, so no hinderance was encountered. A smaller machine, such as an IBM 360 (32 bits/word), would be so limited.

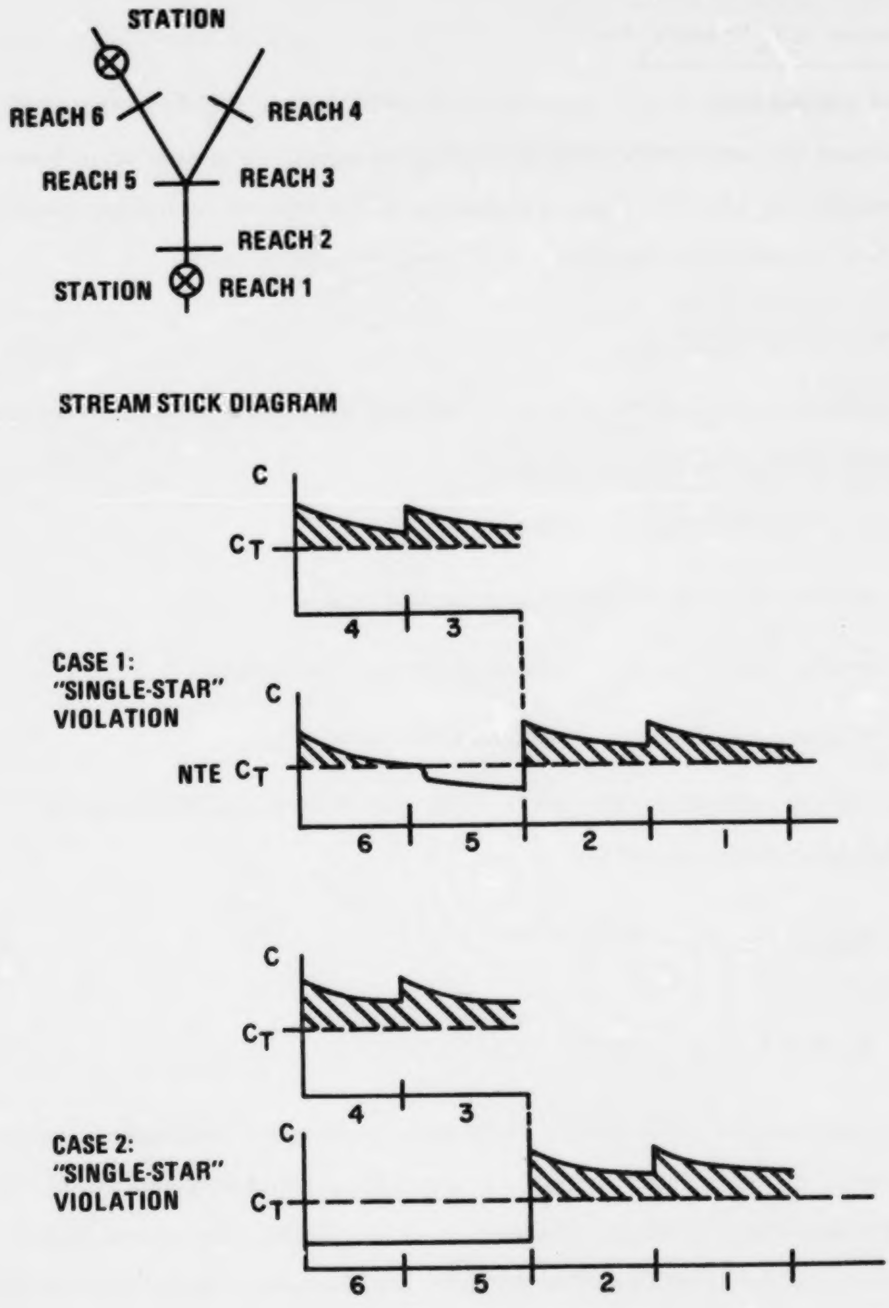

STATION
REACH 6
REACH 4
REACH 5
REACH 3
REACH 2
STATION
REACH 1
STREAM STICK DIAGRAM
C
C_T
4
3
CASE 1:
"SINGLE-STAR"
VIOLATION
C
NTE C_T
6
5
2
1
C
C_T
4
3
CASE 2:
"SINGLE-STAR"
VIOLATION
C
C_T
6
5
2
1

Figure 70. Typical "Single Star" Violation Conditions

Computation of n_v^{**} and n_s^{*}—

The final computation of n_v^{**} (Subroutine COMPT) and n_s^{*} (Subroutine CAPBLE) is performed in a straightforward way using the equations presented in Section VI, equations (21) and (33). The computation of the adjusted sampling interval, Δ_e, is done according to equation (34) or (35), as appropriate.

Estimation of Survivability

As is concluded in Section VI, the basic steps in the estimation of survivability of a system element are:

1. preparation of the transition matrix, $\bar{\bar{S}}$
2. determination of the acceptable failure states
3. computation of the $P_{n_k}(t)$ from the transition matrix
4. computation of survivability, S, from the $P_{n_k}(t)$.

A feature of the estimation process is the use of the Laplace transform to obtain the desired probabilities:

$$\bar{P}(s) = P(o)\,(s\bar{\bar{I}} - \bar{\bar{B}})^{-1} \tag{97}$$

$$P_n(t) = \mathcal{L}^{-1}\,(P_n(s)) \tag{98}$$

Implementation of the survivability estimation process for automatic computation presents an immediate problem. In general, a Laplace transform is logical or mathematical in nature, rather than arithmetical. Automatic digital computers could be programmed to perform the necessary logical manipulations required for a general Laplace transform, but the program necessary to do so would be excessively large and complex. It is preferable to confine use of the computer to arithmetic processes, whenever possible.

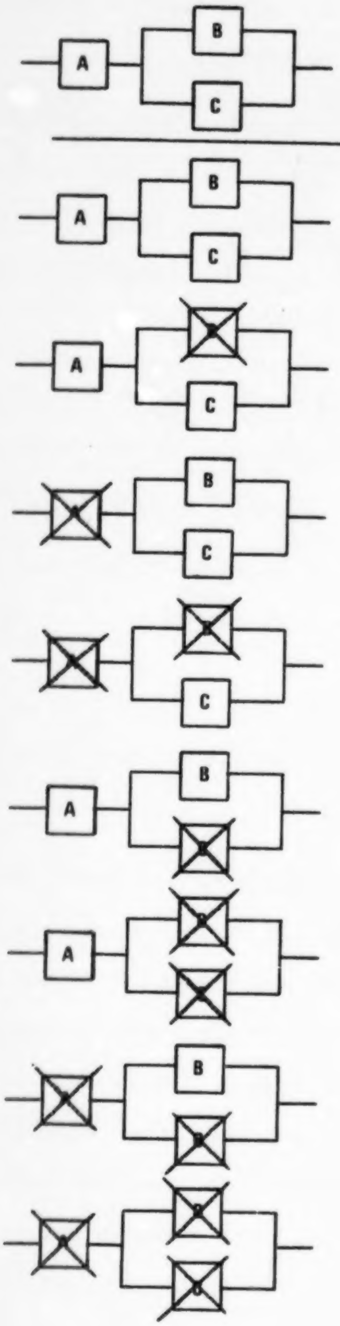
Thus, it is of interest to develop a general algorithm for the computation of $P_n(t)$ that does not require actual manipulation of the Laplace transform. The requirement for such an algorithm is that $P_n(s)$ always have the same general mathematical form. That, in turn, requires that the survivability matrix be formed in a consistent manner each time it is prepared.

The following paragraphs present the development of the general algorithm used in the computation of survivability. The objective of the development is a procedure that meets the limitations imposed by the computer, as discussed above.

Transition Matrix—

The first step in the procedure is the preparation of the transition matrix, $\overline{\overline{S}}$, so that it has a consistent form, no matter how many means are included in the system element, nor what their configuration is.

Such a transition matrix can be generated, if the state numbers are assigned according to a binary scheme. Each means in the system element is identified with a binary place in a binary number that represents the system state number. Failure of the means is associated with a "1" in the corresponding binary place; operating status is associated with a "0". Figure 71 illustrates the assignment of state number for a three means system element. The identification of each means with a binary place is entirely arbitrary, but remains fixed, once done, for each system element. In the case illustrated, means B corresponds to $2^0 = 1$, means A to $2^1 = 2$, and means C to $2^2 = 4$. Thus, when means A and B have both failed, the assigned state number is:



BINARY STATE NO.			DECIMAL STATE NO.
C	A	B	
$2^2=4$	$2^1=2$	$2^0=1$	
0	0	0	= 0
0	0	1	= 1
0	1	0	= 2
0	1	1	= 3
1	0	0	= 4
1	0	1	= 5
1	1	0	= 6
1	1	1	= 7

Figure 71. Assignment of Binary State Number

$$(0 \times 2^2) + (1 \times 2^1) + (1 \times 2^0) = 3 \qquad (99)$$

Use of such a state number assignment scheme assures that the transition matrix will have the form illustrated in Figure 72 for the case of up to four means in the system element. The numbers shown as the matrix elements indicate the binary place corresponding to the failed means that causes a transition from the row state to the column state. The diagonal elements are not shown, for simplicity (see Figure 25). Thus, for example, in the three means case shown in Figure 71 the transition from system state 3 to state 7 corresponds to failure of the means assigned to 2^2, or means C. In generating the transition matrix for the example system, the failure rate λ_c would be inserted in the matrix element $S_{3,7}$. The example given in Section VI (Figures 24 and 25) illustrates such a three means case. In that example, the correspondence is:

2^0 = means A

2^1 = means B

2^2 = means C

and the transition from state 3 to state 7 is related again to λ_c.

As can be seen in Figure 72, a regular and predictable pattern is developed in the transition matrix when the binary scheme is used in assignment of state numbers to system states. The reader can readily convince himself that the pattern recurs for any number of means.

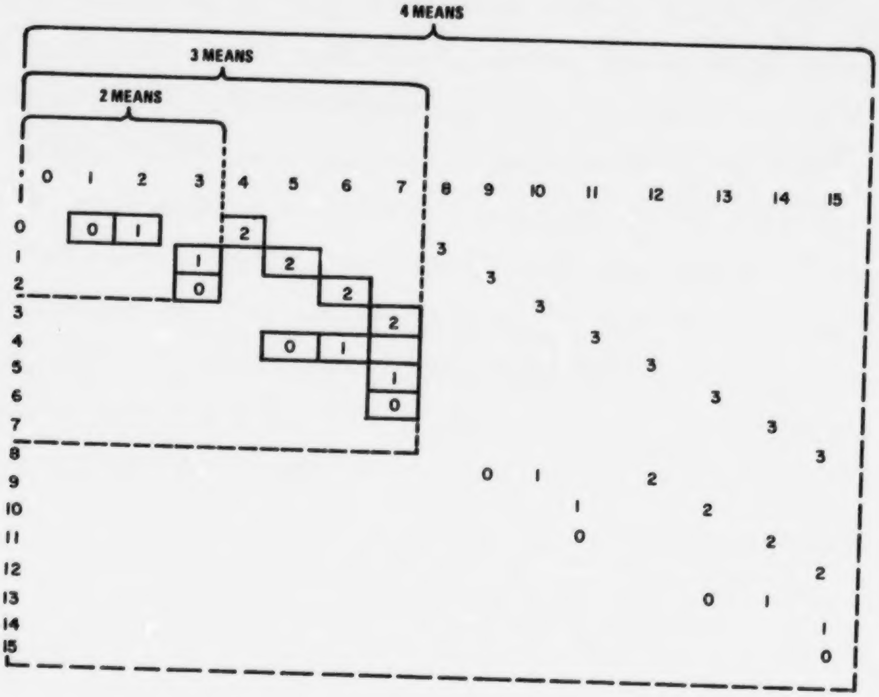

4 MEANS
3 MEANS
2 MEANS

Figure 72. Recursive Pattern in Transition Matrix

State Probabilities—

Skipping over the determination of acceptable states, for the moment, the next step is computation of values for $P_n(t)$, when t equals the system duration. The direct solution of equation (97) requires the logical manipulation of the Laplace transform and is to be avoided in the computer programming. An alternative approach may be developed from a method presented in [13]. It is shown ther that the vector of time derivatives of probability ($P'(t)$) can be formed by:

$$\underline{P}'(t) = \underline{P}(t)\,(\underline{\underline{S}} - \underline{\underline{I}}) \tag{100}$$

where $\underline{\underline{I}}$ is the identity matrix and $\underline{P}(t)$ is as defined in Section VI. Equation (100) represents a set of linear differential equations for which a general solution can be found using Laplace transforms. Since the solution itself is general and can be evaluated arithmetically without resort to the Laplace transform, the desired result is achieved. The general solution is:

$$P_n(t) = \sum_{m=0}^{n-1} \sum_{k=0}^{n-1} \frac{S_{kn} T_{km}}{S_{nn} - S_{mm}} \; e^{-S_{mm} t} + C_{nn} e^{-S_{nn} t} \tag{101}$$

where: T_{km} refers to the coefficient of the $e^{-S_{mm} t}$ term for the $P_k(t)$ equation, the summations are only performed for $(n - 1) \geq 0$, and C_{nn} is a complicated expression not readily stated in general mathematical form. For the case of three means, it would be:

$$C_{nn} = \sum_{a=0}^{n-1} \frac{S_{an}}{S_{aa} - S_{nn}} \left[\sum_{b=0}^{a-1} \frac{S_{ba}}{S_{bb} - S_{nn}} \left(\sum_{c=0}^{b-1} \frac{S_{cb}}{S_{cc} - S_{nn}} \right) \right] \tag{102}$$

For the case of four means, it becomes:

$$C_{nn} = \sum_{a=0}^{n-1} \frac{S_{an}}{S_{aa}-S_{nn}} \left\{ \sum_{b=0}^{a-1} \frac{S_{ba}}{S_{bb}-S_{nn}} \left[\sum_{c=0}^{b-1} \frac{S_{cb}}{S_{cc}-S_{nn}} \left(\sum_{d=0}^{c-1} \frac{S_{dc}}{S_{dd}-S_{nn}} \right) \right] \right\} \qquad (103)$$

And so on for each additional means. It should be noted that this general result is dependent on the organizational form of the survivability matrix as described above.

Computer evaluation of the general solution for probability of survival, $P_n(t)$, is achieved through use of a search algorithm, rather than through a direct arithmetic approach. The search approach permits development of a computer subroutine that is capable of handling any number of means in a system element. A direct arithmetic approach would limit the program to a selected number of means or range of numbers, due to the form of the coefficient C_{nn}.

The search algorithm flowchart is shown in Figure 73. The operation of the algorithm can be illustrated for C_{77} in the case of 3 elemental means as shown in Figure 74. For that case, C_{77} is:

$$\begin{aligned} C_{77} = {} & \frac{S_{67}}{S_{66}-S_{77}} \; \frac{S_{46}}{S_{44}-S_{77}} \; \frac{S_{04}}{S_{00}-S_{77}} \\ & + \frac{S_{67}}{S_{60}-S_{77}} \; \frac{S_{26}}{S_{22}-S_{00}} \; \frac{S_{02}}{S_{00}-S_{77}} \\ & + \frac{S_{57}}{S_{55}-S_{77}} \; \frac{S_{45}}{S_{44}-S_{77}} \; \frac{S_{04}}{S_{00}-S_{77}} \qquad \text{(Cont.)} \end{aligned}$$

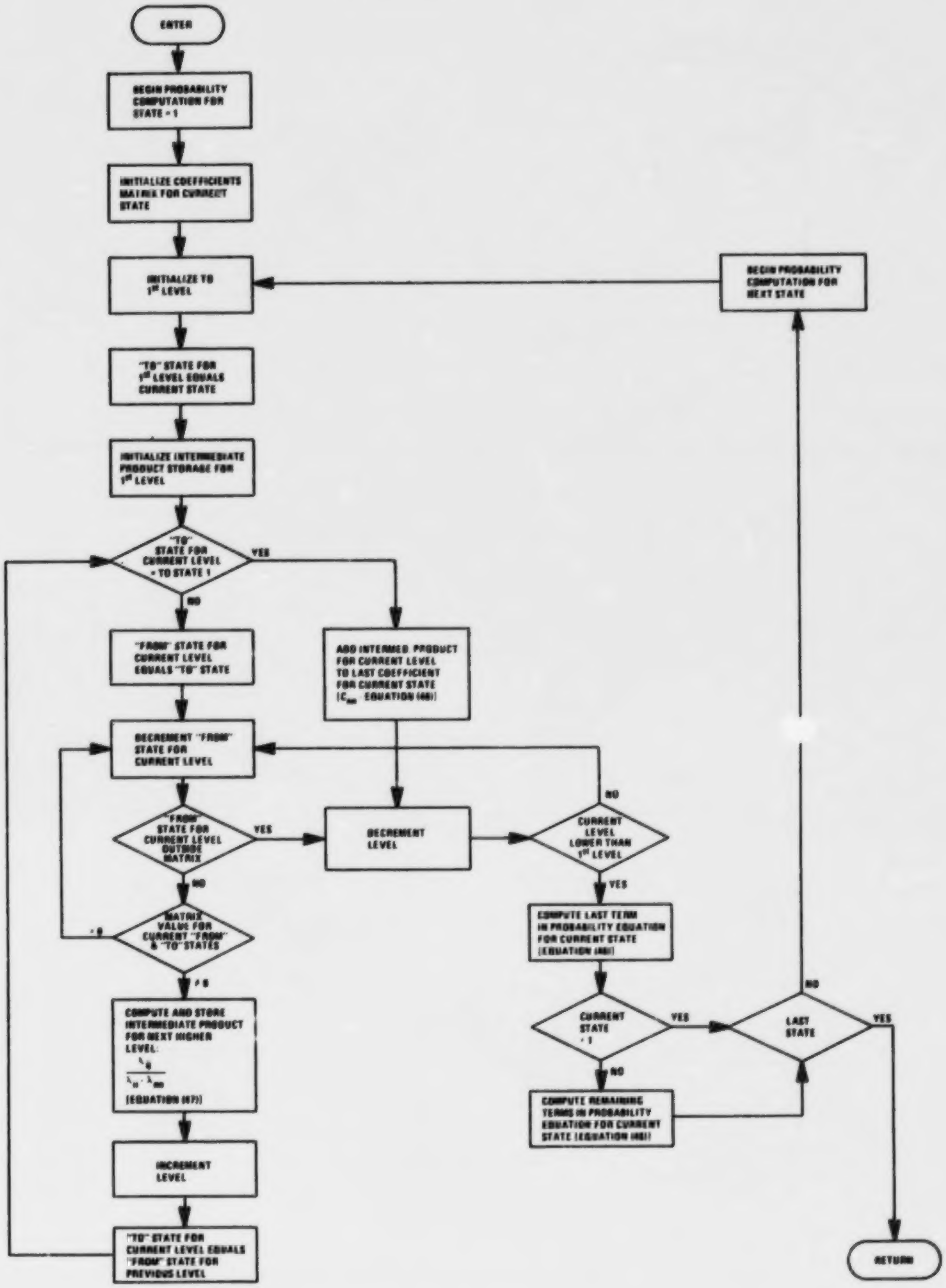

ENTER
BEGIN PROBABILITY COMPUTATION FOR STATE = 1
INITIALIZE COEFFICIENTS MATRIX FOR CURRENT STATE
INITIALIZE TO 1ST LEVEL
"TO" STATE FOR 1ST LEVEL EQUALS CURRENT STATE
INITIALIZE INTERMEDIATE PRODUCT STORAGE FOR 1ST LEVEL
"TO" STATE FOR CURRENT LEVEL = TO STATE 1
YES
NO
"FROM" STATE FOR CURRENT LEVEL EQUALS "TO" STATE
ADD INTERMED. PRODUCT FOR CURRENT LEVEL TO LAST COEFFICIENT FOR CURRENT STATE (C_{mm} EQUATION (46))
DECREMENT "FROM" STATE FOR CURRENT LEVEL
"FROM" STATE FOR CURRENT LEVEL OUTSIDE MATRIX
YES
DECREMENT LEVEL
NO
CURRENT LEVEL LOWER THAN 1ST LEVEL
NO
YES
MATRIX VALUE FOR CURRENT "FROM" & "TO" STATES
= 0
≠ 0
COMPUTE AND STORE INTERMEDIATE PRODUCT FOR NEXT HIGHER LEVEL: $\frac{\lambda_{ij}}{\lambda_{ii} - \lambda_{mm}}$ (EQUATION (47))
INCREMENT LEVEL
"TO" STATE FOR CURRENT LEVEL EQUALS "FROM" STATE FOR PREVIOUS LEVEL
COMPUTE LAST TERM IN PROBABILITY EQUATION FOR CURRENT STATE (EQUATION (48))
CURRENT STATE = 1
YES
NO
COMPUTE REMAINING TERMS IN PROBABILITY EQUATION FOR CURRENT STATE (EQUATION (48))
LAST STATE
NO
YES
BEGIN PROBABILITY COMPUTATION FOR NEXT STATE
RETURN

Figure 73. Flowchart of Search Algorithm

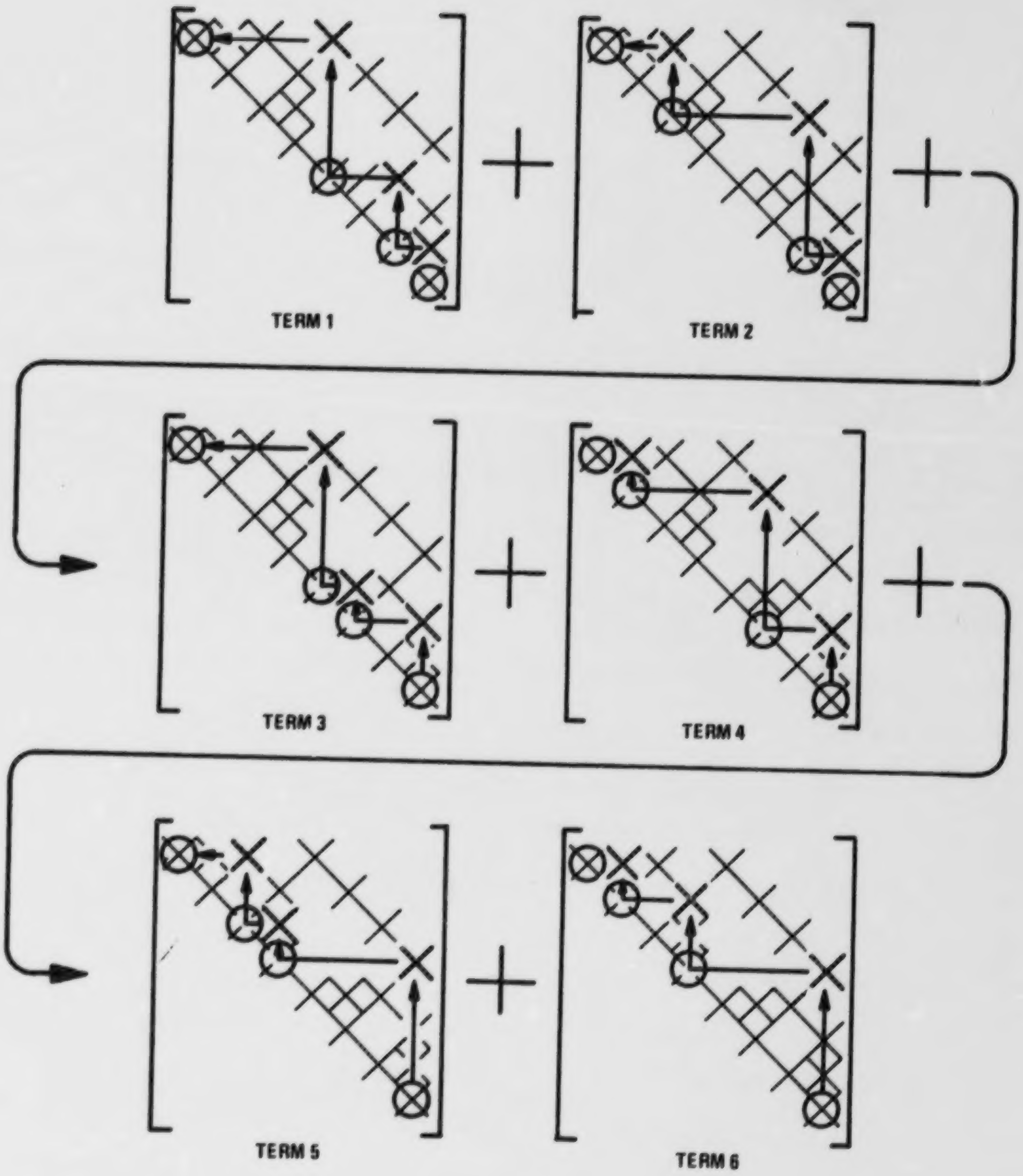

TERM 1
TERM 2
TERM 3
TERM 4
TERM 5
TERM 6

Figure 74. Example of Survivability Computation

$$+ \frac{S_{57}}{S_{55} - S_{77}} \; \frac{S_{15}}{S_{11} - S_{79}} \; \frac{S_{01}}{S_{00} - S_{77}}$$

$$+ \frac{S_{37}}{S_{33} - S_{77}} \; \frac{S_{23}}{S_{22} - S_{77}} \; \frac{S_{02}}{S_{00} - S_{77}}$$

$$+ \frac{S_{37}}{S_{33} - S_{77}} \; \frac{S_{13}}{S_{11} - S_{77}} \; \frac{S_{01}}{S_{00} - S_{77}} \tag{104}$$

The expression for C_{nn} can be formed by generating the products and quotients from the matrix elements as suggested by Figure 74. The remaining terms in the expression for $P_7(t)$ are generated from the previous coefficients as suggested by equation (101).

Computation of Survivability—

The survivability (S) is computed by summing the P_n provided by equation (101) for all the acceptable states. Acceptability of a state is determined by a direct check for continuity of information flow under the state of failure specified by the binary state number. For convenience, the acceptability check is performed in Subroutine SETUP at the time that the state numbering is established.

Estimation of Availability

The similarity between computation of survivability and availability should be clear from the discussion in Section VI. Due to that similarity, the same approach may be used in setting up both transition matrices. The system means are identified with the binary places composing the state number, and matrix elements are equated with mean times to fail or repair as appropriate. The solution of the linear algebraic equations (equation (28) and (29)) may be performed numerically using a procedure such as gaussian elimination. In order to accomodate gaussian elimination, the availability matrix must be in transposed form. That is, the "to-states" must be the rows and the "from-states" must be the columns. Since no other application of the availability transition matrix is made, the computer programming (Subroutine SETUP) automatically generates A in the transposed format. The identity, equation (29), replaces the last row of the matrix, prior to application of the gaussian technique.

APPENDIX F

DESIGN ANALYSIS COMPUTER PROGRAMS

The program flowcharts and program listings for the design analysis computer programs are presented in this appendix. Only those programs and sub-programs specific to the design analysis are flowcharted. The appendix does contain the complete program listing, including the RIBAM subroutines. Detailed information on the RIBAM subroutines may be found in [7]. Section VII and Appendix E of this report contains a discussion of the development and underlying principles of these programs.

The programs listed in this appendix are written in FORTRAN IV, for use on the CDC 6700. They have been compiled under the CDC RUN 76 compiler and run under the KRONOS 2.0 operating system (version 12), as supported by the Raytheon Scientific Computer Center, Bedford, Massachusetts. The original card decks are punched in BCDIC.

With the exception of the GSTAPE subroutine, the reader is referred to Section VII and Appendix E for textual material on these programs.

PROGRAM MAIN

```
      PROGRAM MAIN (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE2)
      COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40), IREAD(20),
     * MTTFA(300,2), MTTFS(300,2), MTTRA(300,2), LIST(4), COST(4),
     * MEMBER(100,2), CSTINC(100,2), SDATA(10), NDATA(10), MSYS(10,23),
     * NSAC(64), MINC(5), MPATH(5), MEMB(10), NSTATE(5), PFAIL(10),
     * PCHK(10), NTRANS(5), LEVEL(10), TRANS(64,64), AVAIL(40)
      COMMON COEF(64,64), SRV(40), PROD(65), PROB(65), NST(64),
     * NSFR(64), EFF(40),DUMMY(3425)
      COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JQ, JU, JX, JY,
     * JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSEAS, TA,AACUP,BBCUP,
     *CCUP1,CCUP2,CCUP3,CCUP4,CCUP5,CCUP6,CCUP7, CCRON, A3, DBENTH,
     * ELEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NI, NINIT, NOX, MZ,
     * MY, MZY, NJUNC, NTRIB, NREA, NACC, DENOM, ESYS, TOTCST, CHECK
      COMMON/BLK/MASK(40)
      DATA   (MASK(I),I=1,40)/0000001B,0000002B,0000004B,0000010B,0000020
     *B,0000040B,0000100B,0000200B,0000400B,0001000B ,0002000B ,
     *0004000B ,0010000B, 0020000B,0040000B,0100000B,0200000B,
     *0400000B,1000000B, 2000000B,4000000B,10000000B,20000000B,
     *40000000B,100000000B,200000000B,400000000B, 1000000000B,2000000000
     *B,4000000000B,10000000000B,20000000000B,40000000000B,100000000000B
     *,200000000000B,400000000000B, 1000000000000B,2000000000000B,
     *4000000000000B,10000000000000B/
      COMMON/BLOCK2/TIME,NMR,DTYPE,POPT
      LOGICAL MASK,DTYPE
      NI=5
      NJ=6
C                                                                       30
      CALL RPC
      CALL RSDD
      DENOM=0.0
      DO 300 JU = 1,NPAR
      NUM = NVAR(JU)
      IF (IREAD(NUM).EQ.1) GO TO 200
      CALL RCHAR
  200 CALL QTCAL
      IF (IREAD(NUM).EQ.1) GO TO 300
      CALL EXPDUR
      CALL COMPT
      IF (.NOT.DTYPE) GO TO 500
      CALL PPDES
      GO TO 300
  500 CALL CAPBLE
  300 CONTINUE
      IF (DTYPE) GO TO 600
      CALL RMTTF
      DO 2 I = 1,NREA
      EFF(I)   = 0.0
    2 CONTINUE
      DO 400 JU=1,NPAR
      NUM = NVAR(JU)
      IF (IREAD(NUM).EQ.1) GO TO 400
      CALL LMNTEFF
  400 CONTINUE
      CALL SYSEFF
      CALL CALCST
      CSTEFF = TOTCST / ESYS
      PRINT 3000,TOTCST,CSTEFF
 3000 FORMAT (//10X,13HTOTAL COST = ,E13.5,///,10X,12HCOST/EFF. = ,E13.5
     *)
  600 STOP
      END
```

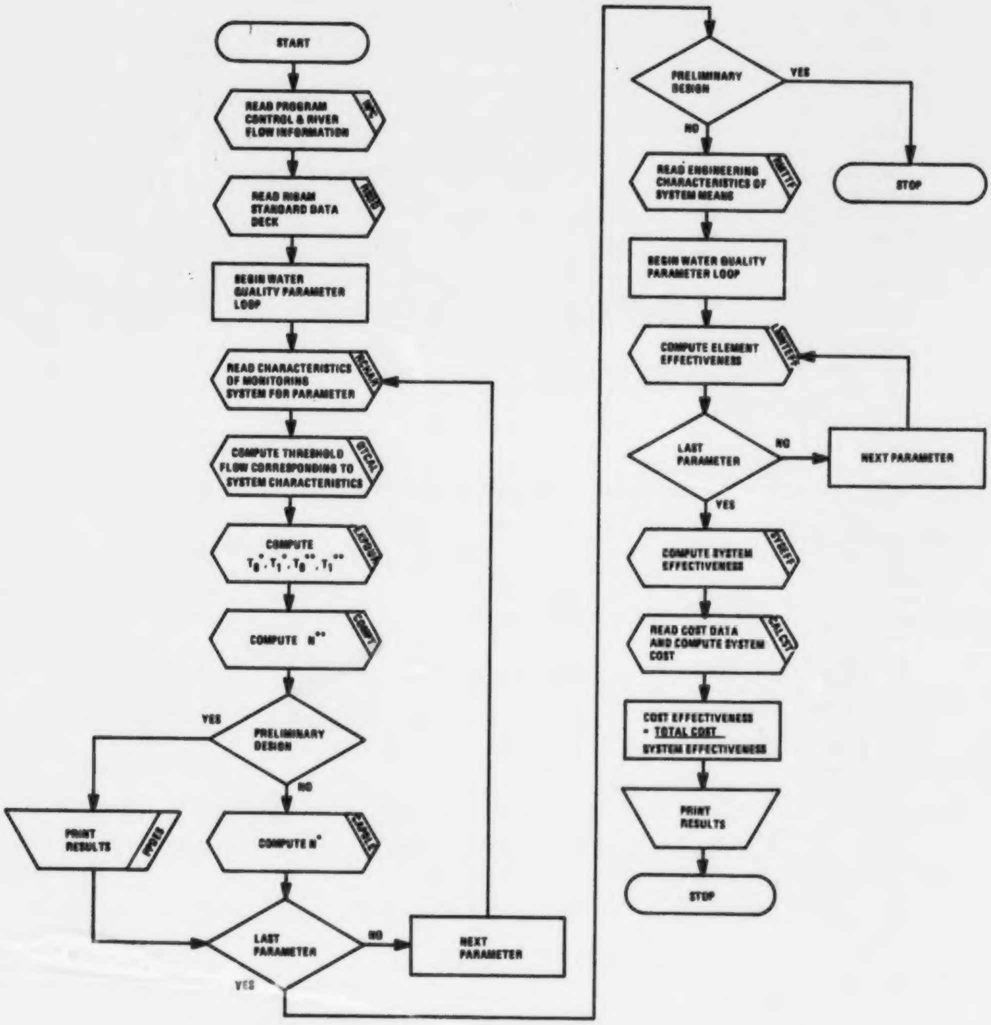

START
READ PROGRAM CONTROL & RIVER FLOW INFORMATION
READ RISAM STANDARD DATA DECK
BEGIN WATER QUALITY PARAMETER LOOP
READ CHARACTERISTICS OF MONITORING SYSTEM FOR PARAMETER
COMPUTE THRESHOLD FLOW CORRESPONDING TO SYSTEM CHARACTERISTICS
QTCAL
COMPUTE $T_0^*, T_1^*, T_0^{**}, T_1^{**}$
COMPUTE N^{**}
PRELIMINARY DESIGN
YES
NO
PRINT RESULTS
COMPUTE N^*
LAST PARAMETER
NO
YES
NEXT PARAMETER
PRELIMINARY DESIGN
YES
NO
STOP
READ ENGINEERING CHARACTERISTICS OF SYSTEM MEANS
BEGIN WATER QUALITY PARAMETER LOOP
COMPUTE ELEMENT EFFECTIVENESS
LAST PARAMETER
NO
YES
NEXT PARAMETER
COMPUTE SYSTEM EFFECTIVENESS
READ COST DATA AND COMPUTE SYSTEM COST
CALCST
COST EFFECTIVENESS = TOTAL COST / SYSTEM EFFECTIVENESS
PRINT RESULTS
STOP

Figure 75. Flowchar t for MAIN Program

SUBROUTINE RPC

```
      SUBROUTINE RPC
      COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40),
     * IREAD(20), CONDE(20,2), CONDI(20,18), DATA(40,94), FINIS(40,9),
     * G(40,20,5), HWFLOW(10,12), INIT(10), IORD(20,20), MONTH(12),
     * JUNC(10,3), TITLE(20), QSCAL(5), TEMPR(40), CMAXM(40,5),
     * CMINUX(40,5), TLMAXM(40,5), XL(40), CT(40)
      COMMON EPSI(40), SEPSI(40), XACT(40,5), CMINUM(40,5), TMINUM(40),
     * CMINDM(40,5), NDOPT(40), K2OPT(40), NSOC(20,28), NSTAT(20),
     * XORD(5),YORD(5), QT(40,9), MSK(40,5), NJC(10), ICPY(10),
     * FIRST(40), STATE(40), NDAYS(40), STATE1(40), FIRST1(40)
      COMMON KONTS(40,2), NTOTS(40,2), NDAYS1(40), KOUNT(40,2), PREV(40)
     * , NTOT(40,2), PREV1(40), Q(31,20), TS(40,2), TSS(40,2), TUP(40),
     * TDOWN(40), DELTA(40), HTH(40), CMINDX(40,5), TMINUX(40),
     * TMINDX(40),TMINDM(40),X1(40,5,2),Y1(40,5),DEFC(40),TCOMP(40,2)
      COMMON CINT(10,4), TLEN(10), NSEG(20), MNPLCY(40),TL(40)
      COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JQ, JU, JX, JY,
     * JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSFAS, TA,AACUP,BBCUP,
     *CCUP1,CCUP2,CCUP3,CCUP4,CCUP5,CCUP6,CCUP7, CCRON, A3, DBENTH,
     * ELEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NI, NINIT, NOX, MZ,
     * MY, MZY, NJUNC, NTRIB, NREA, NACC, DENOM, ESYS, TOTCST, CHECK
      COMMON/BLK/MASK(40)
      COMMON/BLOCK2/TIME,NMR,DTYPE,POPT
      LOGICAL MASK,CHECK,DTYPE,POPT
      DATA END/4HEND /
      DO 50 K = 1,20
   50 NSTAT(K) = 0
C  READ PRORAM CONTROL CARD
      READ (NI,100) DUM1,DUM2,DTYPE,(IREAD(I),I=1,20),TIME,NMR,(QSCAL(I)
     *,I=1,5),POPT
  100 FORMAT (2A4,L1,1X,20I1,F5.0,I5,5F5.0,4X,L1)
      IF (POPT) WRITE (NJ,150) DTYPE,TIME,NMR,(QSCAL(I),I=1,5)
  150 FORMAT (1H1,//10X,*DESIGN TYPE = *,L1,* SYSTEM DUR. = *,F7.2,* NO.
     * OF MONTHS = *,I5,* FLOW SCALING FACTORS = *,5F5.1)
C  COMPUTE THE NUMBER OF PARAMETERS TO BE SIMULATED
      NPAR = 0
      DO 200 I = 1,20
      IF (IREAD(I).GT.0) NPAR = NPAR + 1
  200 CONTINUE
      DO 300 I = 1,5
      IF (QSCAL(I).EQ.0.) QSCAL(I) = 1.
  300 CONTINUE
      IF (POPT) WRITE (NJ,250)
  250 FORMAT (///10X,* STA. NO.      STA. I.D.       SEG. NO.     SEG. A
     *SSOCIATION*,///)
    1 READ (NI,400) DUM1,NGS,NSTAT(NGS),NSEG(NGS),(NSOC(NGS,I),I=1,28)
  400 FORMAT (A4,4X,I2,2X,I8,1X,I2,1X,28I2)
      IF (DUM1.EQ.END) 2,3
    3 IF (POPT) WRITE (NJ,350) NGS,NSTAT(NGS),NSEG(NGS),(NSOC(NGS,I),I=1
     *,28)
  350 FORMAT (/13X,I3,9X,I8,11X,I2,6X,28I2)
      GO TO 1
    2 CHECK = .FALSE.
C  SET UP CHECK FOR SEGMENT - GAUGING STATION ASSOCIATION
      DO 600 NGS = 1,20
      IF (NSTAT(NGS).EQ.0) GO TO 600
      DO 500 I = 1,28
      IF (NSOC(NGS,I).EQ.0) GO TO 500
      IT = NSOC(NGS,I)
      CHECK = CHECK.OR.MASK(IT)
  500 CONTINUE
  600 CONTINUE
      RETURN
      END
```

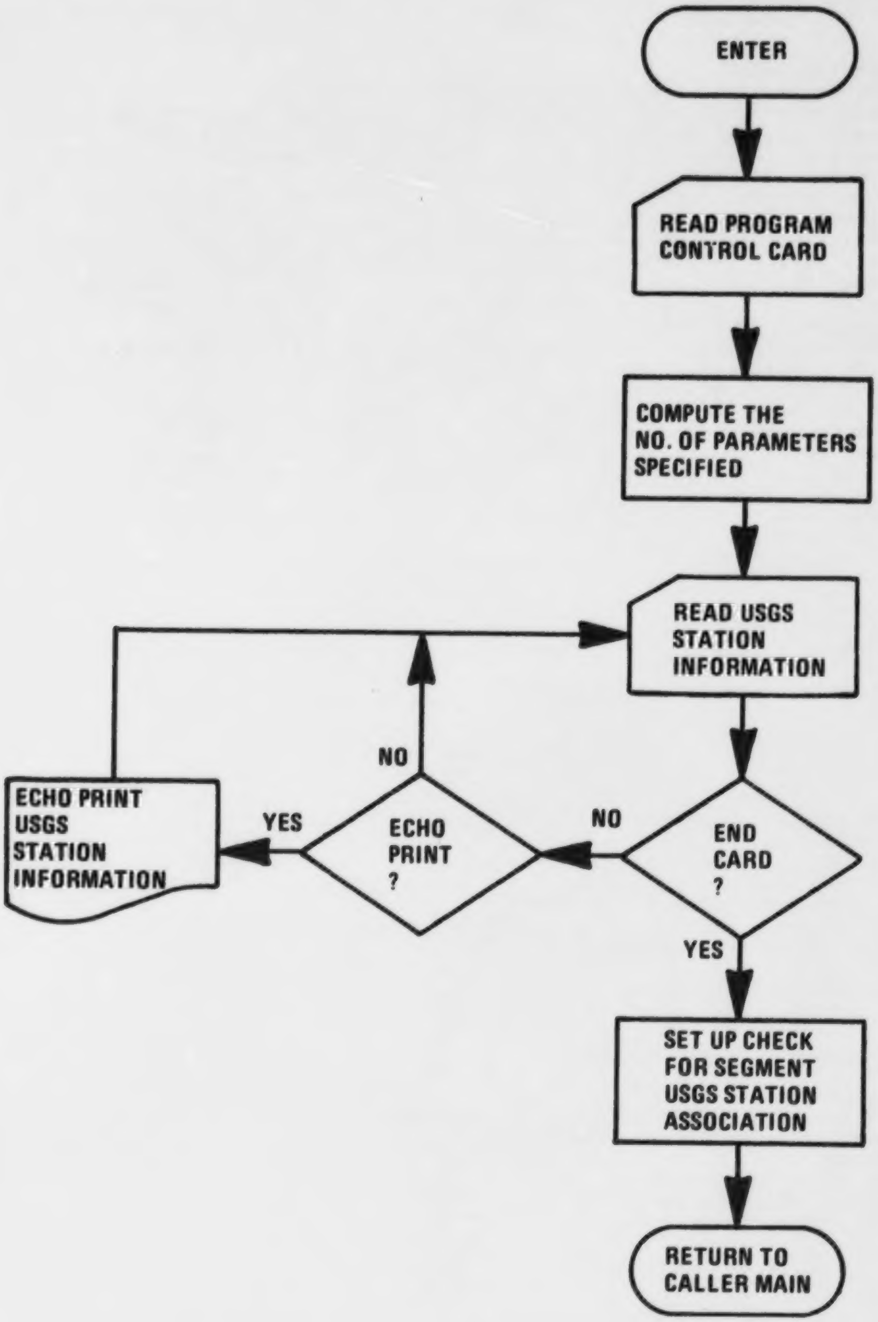

ENTER
READ PROGRAM CONTROL CARD
COMPUTE THE NO. OF PARAMETERS SPECIFIED
READ USGS STATION INFORMATION
END CARD ?
NO
ECHO PRINT ?
NO
YES
ECHO PRINT USGS STATION INFORMATION
YES
SET UP CHECK FOR SEGMENT USGS STATION ASSOCIATION
RETURN TO CALLER MAIN

Figure 76. Flowchart for Subroutine RPC

SUBROUTINE RSDD

```
      SUBROUTINE RSDD
      COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40),
     * IREAD(20), CONDE(20,2), CONDI(20,18), DATA(40,94), FINIS(40,9),
     * G(40,20,5), HWFLOW(10,12), INIT(10), IORD(20,20), MONTH(12),
     * JUNC(10,3), TITLE(20), QSCAL(5), TEMPR(40), CMAXM(40,5),
     * CMINUX(40,5), TLMAXM(40,5), XL(40), CT(40)
      COMMON EPSI(40), SEPSI(40), XACT(40,5), CMINUM(40,5), TMINUM(40),
     * CMINDM(40,5), NDOPT(40), K20PT(40), NSOC(20,28), NSTAT(20),
     * XORD(5),YORD(5), QT(40,9), MSK(40,5), NJC(10), ICPY(10),
     * FIRST(40), STATE(40), NDAYS(40), STATE1(40), FIRST1(40)
      COMMON KONTS(40,2), NTOTS(40,2), NDAYS1(40), KOUNT(40,2), PREV(40)
     * , NTOT(40,2), PREV1(40), Q(31,20), TS(40,2), TSS(40,2), TUP(40),
     * TDOWN(40), DELTA(40), HTH(40), CMINDX(40,5), TMINUX(40),
     * TMINDX(40),TMINDM(40),X1(40,5,2),Y1(40,5),DEFC(40),TCOMP(40,2)
      COMMON CINT(10,4), TLEN(10), NSEG(20), MNPLCY(40),TL(40)
      COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JQ, JU, JX, JY,
     * JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSEAS, TA,AACUP,BBCUP,
     *CCUP1,CCUP2,CCUP3,CCUP4,CCUP5,CCUP6,CCUP7, CCRON, A3, DBENTH,
     * ELEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NI, NINIT, NOX, MZ,
     * MY, MZY, NJUNC, NTRIB, NREA, NACC, DENOM, ESYS, TOTCST, CHECK
      DATA ENDF/4HENDF/                                                   170
      LOGICAL IMPL
      DO 40 I = 1,40
   40 IMPL(I) = .FALSE.
      DO 3333 I = 1,20
      DO 3333 J= 1,18
 3333 CONDI (I,J)=0.
      DO 788  I = 1,10
      DO 788 J=1,12
  788 HWFLOW(I,J) = 0.0
      NR=5
C
C                             READ FILE A THRU FILE F-3                   300
C
C            FILE A  - BASIN TITLE                                        340
   41 READ (NI,1) DUM1,DUM2,(TITLE(I),I=1,18)
    1 FORMAT (20A4)                                                       190
      READ (NI,1) DUM1,DUM2                                               210
      IF (DUM1.NE.ENDF) GO TO 777                                         240
C            FILE B  - BASIN COMPONENTS                                   260
      READ (NI,26) DUM1,DUM2,NINIT,NJUNC,NREA,NTRIB,ELEV
   26 FORMAT (2A4,5X,I2,5X,3(4X,I2,4X),F10.0)
C
      READ (NI,1) DUM1,DUM2                                               400
      IF (DUM1.NE.ENDF) GO TO 777                                         420
C
C            RILE C  - REACH ORDER
C
      DO 10 K=1,NTRIB                                                     500
      READ (NI,3) DUM1,DUM2,I,(IORD(I,J),J=1,20)                          510
    3 FORMAT (2A4,3X,I2,7X,20(1X,I2))                                     52
   10 CONTINUE                                                            550
      READ (NI,1) DUM1,DUM2                                               560
      IF (DUM1.NE.ENDF) GO TO 777                                         580
      IF (NJUNC.EQ.0) GO TO 887
C
C            FILE D  - JUNCTIONS
C
```

```
      DO 11 K=1,NJUNC
      READ (NI,33) DUM1,DUM2,I,(JUNC(I,J),J=1,3)
   33 FORMAT (2A4,13X,I2,2X,3(4X,I2,4X))
   11 CONTINUE
      READ (NI,1) DUM1,DUM2
      IF (DUM1.NE.ENDF) GO TO 777
C
C
C            FILE E - HEADWATER CONCENTRATIONS
C
  887 DO 373 MZY = 1,6
      CALL RCOND
      READ (NI,1) DUM1,DUM2
      IF (DUM1.NE.ENDF) GO TO 777
  373 CONTINUE
C
C            FILE F-1  -  DATA(I,1) THRU DATA(I,6)
C
      DO 100 K=1,NREA
      READ (NI,105) DUM1,DUM2,I,(DATA(I,J),J=1,6)
  105 FORMAT (2A4,8X,I2,2X,6(2X,F8.0))
  100 CONTINUE
      READ (NI,1) DUM1,DUM2
      IF (DUM1.NE.ENDF) GO TO 777
C
C            FILE F-2  -  DATA(I,7),K20PT(I),DATA(I,8) THRU DATA(I,13)
C                      -  MUNICIPAL FLOWS,K17 OPTION , REAERATION RAOE INFOH3
C
      DO 150 K=1,NREA
      READ (NI,608) DUM1,DUM2,I,DATA(I,7),K20PT(I),(DATA(I,J),J=8,13)
  608 FORMAT (2A4,8X,I2,4X,F8.0,4X,I2,2X,6F7.0)
150   CONTINUE
      READ (NI,1) DUM1,DUM2
      IF (DUM1.NE.ENDF) GO TO 777
C
C
C            FILE F-3  - NDOPT(I), DATA(I,14) - DATA(I,16),  RIDENT(I,J)
C                      - DEPTH OPTION, DEPTH INFORMATION, REACH IDENTIFICATION
C
      DO 160 K=1,NREA
      READ (NI,811) DUM1,DUM2,I,NDOPT(I),(DATA(I,J),J=14,16)
  811 FORMAT (2A4,2(8X,I2),2X,3(2X,F8.0))
160   CONTINUE
      READ (NI,1) DUM1,DUM2
      IF (DUM1.NE.ENDF) GO TO 777
C
C            READ FILE F-4 THRU F-9,  DATA(I,17) - DATA(I,84)
C            - REACH-BY-REACH CONCENTRATIONS OF ALL EFFLUENT SOURCE TYPES
C            - FOR ALL 17 CONSTITUENTS
C
      DO 780 MZ = 1,6
      CALL RDATA
      READ (NI,1) DUM1,DUM2
      IF (DUM1.NE.ENDF) GO TO 777
  780 CONTINUE
C
C
C            READ FILE G, MONTH INDICATOR
C
      READ (NI,6) DUM1,DUM2,(MONTH(I),I=1,12)
    6 FORMAT (2A4,12X,12(2X,I1,2X))
      READ (NI,1) DUM1,DUM2
      IF (DUM1.NE.ENDF) GO TO 777
```

```
C
C          READ FILE H,  MEAN MONTHLY HEADWATER FLOWS
C
      DO 250 K=1,NINIT
      READ (NI,260) DUM1,DUM2,I,(HWFLOW(I,J),J=1,12)                    1280
  260 FORMAT (2A4,3X,I2,7X,12F5.0)                                      1290
  250 CONTINUE                                                          1300
      READ (NI,1) DUM1,DUM2                                             2380
      IF (DUM1.NE.ENDF) GO TO 777 .                                     1330
C                                                                       1350
      DO 15 K=1,12                                                      1420
      IF (MONTH(K)) 22,15,22                                            1500
   22 NSEAS = K
   15 CONTINUE
C                                                                       2930
C          READ FILE I, REACH-BY-REACH TEMPERATURE AND HEIGHT OF DAMS
C
      DO 690 IX = 1,NREA
      READ (NI,687) DUM1,DUM2,I,TEMPR(I),HTH (I)
  690 CONTINUE
  687 FORMAT (2A4,8X,I2,2X,6(2X,F8.0))
      READ (NI,1) DUM1,DUM2
      IF (DUM1.NE.ENDF) GO TO 777
C
C          READ FILE J
C                         - COUPLING COEFFICIENTS,BENTHOS
C
      READ (NI,786) DUM1,DUM2,AACUP,BBCUP,CCUP1,CCRON,CCUP2,CCUP3,CCUP4,
     * CCUP5,CCUP6,CCUP7,DBENTH,A3
  786 FORMAT (2A4,2X,14F5.0)
      READ (NI,1) DUM1,DUM2
      IF (DUM1.NE.ENDF) GO TO 777
C
C          READ REACTION RATE COEFFICIENTS FOR NON
C               CONSERVATIVE PARAMETERS,EXCEPT D.O.
C          READ FILE K                          DATA(I,85) - DATA(I,94)
C                         -REACH-BY-REACH REACTION RATES
C
      DO 767 MY = 1,3
      CALL RDRATE
      READ (NI,1) DUM1,DUM2
      IF (DUM1.NE.ENDF) GO TO 777
  767 CONTINUE
      GO TO 7777
  777 WRITE (NJ,778)                                                    2960
  778 FORMAT (1H1,21X,34H* * * * * * * * * * * * * * * * * ,            1740
     *                 33H* * * * * * * * * * * * * * * * *,//,         1750
     *             22X,34H* E X E C U T I O N   W A S   T E ,           2990
     *                 33HR M I N A T E D   B E C A U S E *,//,         3000
     *             22X, 1H*,31X,3HO F,31X,1H*,//,                       3010
     *             22X,34H*             E R R O R S   I N  ,            3020
     *                 33HI N P U T   D A T A              *,//,        3030
     *             22X,34H* * * * * * * * * * * * * * * * * ,           304
     *                 33H* * * * * * * * * * * * * * * * *)            3050
      STOP
 7777 RETURN
      END
```

SUBROUTINE RCOND

```
      SUBROUTINE RCOND
      COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40),
     * IREAD(20), CONDE(20,2), CONDI(20,18), DATA(40,94), FINIS(40,9),
     * G(40,20,5), HWFLOW(10,12), INIT(10), IORD(20,20), MONTH(12),
     * JUNC(10,3), TITLE(20), QSCAL(5), TEMPR(40), CMAXM(40,5),
     * CMINUX(40,5), TLMAXM(40,5), XL(40), CT(40)
      COMMON EPSI(40), SEPSI(40), XACT(40,5), CMINUM(40,5), TMINUM(40),
     * CMINDM(40,5), NDOPT(40), K2OPT(40), NSOC(20,28), NSTAT(20),
     * XORD(5),YORD(5), QT(40,9), MSK(40,5), NJC(10), ICPY(10),
     * FIRST(40), STATE(40), NDAYS(40), STATE1(40), FIRST1(40)
      COMMON KONTS(40,2), NTOTS(40,2), NDAYS1(40), KOUNT(40,2), PREV(40)
     * , NTOT(40,2), PREV1(40), Q(31,20), TS(40,2), TSS(40,2), TUP(40),
     * TDOWN(40), DELTA(40), HTH(40), CMINDX(40,5), TMINUX(40),
     * TMINDX(40),TMINDM(40),X1(40,5,2),Y1(40,5),DEFC(40),TCOMP(40,2)
      COMMON CINT(10,4), TLEN(10), NSEG(20), MNPLCY(40),TL(40)
      COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JQ, JU, JX, JY,
     * JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSFAS, TA,AACUP,BBCUP,
     *CCUP1,CCUP2,CCUP3,CCUP4,CCUP5,CCUP6,CCUP7, CCRON, A3, DBENTH,
     * ELEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NI, NINIT, NOX, MZ,
     * MY, MZY, NJUNC, NTRIB, NREA, NACC, DENOM, ESYS, TOTCST, CHECK
C
C           READS CONCENTRATIONS OF SIMULATED PARAMETERS IN ALL HEADWATERS
C
      LINIT= 3*(MZY-1)+1
      NFIN = 3*MZY
      IF (MZY.EQ.1) NRTN=0
C
C           DETERMINE WHICH OF THE EIGHT POSSIBLE COMBINATIONS
C           - MUST BE READ IN FOR EACH BLOCK OF THREE PARAMETERS
      NSUM = 1
      DO 83 LBAR=1,3
      IRY = 3*(MZY-1) + LBAR
      IRZ = IREAD(IRY)
      IF(IRZ.EQ.0) GO TO 83
      GO TO (11,12,13),LBAR
   11 LT = 1
      GO TO 14
   12 LT = 2
      GO TO 14
   13 LT = 4
   14 NSUM = NSUM + LT
      NRTN =NRTN + 1
      NVAR(NRTN) = IRY
   83 CONTINUE
C
C           READ AND PRINT HEADWATER CONCENTRATIONS OF ONLY THOSE PARAMETERS
C           - TO BE SIMULATED
      GO TO (1,2,3,4,5,6,7,8),NSUM
    1 DO 40 K=1,NINIT
      READ (NI,101) BLANK1
   40 CONTINUE
      GO TO 9
    2 DO 41 K=1,NINIT
      READ (NI,102) DUM1,DUM2,I,CONDI(I,LINIT)
      INIT(K) = I
   41 CONTINUE
      GO TO 9
    3 DO 42 K=1,NINIT
      READ (NI,103) DUM1,DUM2,I,CONDI(I,LINIT+1)
      INIT(K) = I
```

```
 42 CONTINUE
    GO TO 9
  4 DO 43 K=1,NINIT
    READ (NI,104) DUM1,DUM2,I,CONDI(I,LINIT)   ,CONDI(I,LINIT+1)
    INIT(K) = I
 43 CONTINUE
    GO TO 9
  5 DO 44 K=1,NINIT
    READ (NI,105) DUM1,DUM2,I,CONDI(I,NFIN)
    INIT(K) = I
 44 CONTINUE
    GO TO 9
  6 DO 45 K=1,NINIT
    READ (NI,106) DUM1,DUM2,I,CONDI(I,LINIT), CONDI(I,NFIN)
    INIT(K) = I
 45 CONTINUE
    GO TO 9
  7 DO 46 K=1,NINIT
    READ (NI,107) DUM1,DUM2,I,CONDI(I,LINIT),CONDI(I,NFIN)
    INIT(K) = I
 46 CONTINUE
    GO TO 9
  8 DO 47 K=1,NINIT
    READ (NI,108) DUM1,DUM2,I,(CONDI(I,L),L=LINIT,NFIN)
    INIT(K) = I
 47 CONTINUE
101 FORMAT (A4)
102 FORMAT (2A4,8X,I2,4X,F8.2)
103 FORMAT (2A4,8X,I2,24X,F8.0)
104 FORMAT (2A4,8X,I2,4X,F8.0,12X,F8.0)
105 FORMAT (2A4,8X,I2,44X,F8.0)
106 FORMAT (2A4,8X,I2,4X,F8.0,32X,F8.0)
107 FORMAT (2A4,8X,I2,24X,F8.0,12X,F8.0)
108 FORMAT (2A4,8X,I2,4X,F8.0,2(12X,F8.0))
  9 RETURN
    END
```

SUBROUTINE RDATA

```
      SUBROUTINE RDATA
      COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40),
     * IREAD(20), CONDE(20,2), CONDI(20,18), DATA(40,94), FINIS(40,9),
     * G(40,20,5), HWFLOW(10,12), INIT(10), IORD(20,20), MONTH(12),
     * JUNC(10,3), TITLE(20), OSCAL(5), TEMPR(40), CMAXM(40,5),
     * CMINUX(40,5), TLMAXM(40,5), XL(40), CT(40)
      COMMON EPSI(40), SEPSI(40), XACT(40,5), CMINUM(40,5), TMINUM(40),
     * CMINDM(40,5), NDOPT(40), K2OPT(40), NSOC(20,28), NSTAT(20),
     * XORD(5),YORD(5), QT(40,9), MSK(40,5), NJC(10), ICPY(10),
     * FIRST(40), STATE(40), NDAYS(40), STATF1(40), FIRST1(40)
      COMMON KONTS(40,2), NTOTS(40,2), NDAYS1(40), KOUNT(40,2), PREV(40)
     * , NTOT(40,2), PREV1(40), Q(31,20), TS(40,2), TSS(40,2), TUP(40),
     * TDOWN(40), DELTA(40), HTH(40), CMINDX(40,5), TMINUX(40),
     * TMINDX(40),TMINDM(40),X1(40,5,2),Y1(40,5),DEFC(40),TCOMP(40,2)
      COMMON CINT(10,4), TLEN(10), NSEG(20), MNPLCY(40),TL(40)
      COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JQ, JU, JX, JY,
     * JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSEAS, TA,AACUP,BBCUP,
     *CCUP1,CCUP2,CCUP3,CCUP4,CCUP5,CCUP6,CCUP7, CCRON, A3, DBENTH,
     * ELEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NI, NINIT, NOX, MZ,
     * MY, MZY, NJUNC, NTRIB, NREA, NACC, DENOM, ESYS, TOTCST, CHECK
C
C           READS CONCENTRATIONS OF EFFLUENT SOURCES FOR SIMULATED PARAMETERS
C           - AND ALL REACHES
C
      KPP = 0
      IF (MZ.EQ.6) KPP=2
      NSUM = 1
      LINIT = 6*(MZ-1) + 1
      LMID = LINIT + 1
      NFIN  = 6*(MZ-1) + 3
C
C           DETERMINES WHICH OF THE EIGHT POSSIBLE COMBINATIONS
C           - MUST BE READ IN  FOR EACH BLOCK OF THREE PARAMETERS
C
      DO 750  IBAR = 1,3
      IRY = 3*(MZ-1)+IBAR
      IRX = IREAD(IRY)
      IF (IRX.EQ.0) GO TO 750
      GO TO (1,2,3), IBAR
    1 IRZ = 1
      GO TO 4
    2 IRZ = 2
      GO TO 4
    3 IRZ = 4
C
C
    4 NSUM = NSUM + IRZ
  750 CONTINUE
C
      KS = 15 + 2*LINIT
      KT = 15 + 2*NFIN
      KP = KT + 1
      KR = KS + 3
      KQ = KS + 2
      LS  = 21 + 2*LINIT - KPP
      LT  = 21 + 2*NFIN - KPP
      LP  = LT + 1
      LR  = LS + 3
      LQ  = LS + 2
C
```

```
C          READS CONCENTRATIONS FOR ONLY THOSE PARAMETERS TO BE SIMULATED
C
      GO TO (11,12,13,14,15,16,17,18),NSUM
C
   11 DO 21 K = 1,NREA
      READ (NI,101) BLANK1
      READ (NI,101) BLANK1
   21 CONTINUE
      GO TO 9
C
   12 DO 23 K = 1,NREA
      READ (NI,102)  DUM1,DUM2,I,DATA(I,KS),DATA(I,KS+1)
      READ  (NI,102) DUM1,DUM2,I,DATA(I,LS),DATA(I,LS+1)
   23 CONTINUE
      GO TO 9
C
   13 DO 24  K=1,NREA
      READ (NI,103) DUM1,DUM2,I,DATA(I,KS+2) ,DATA(I,KS+3)
      READ  (NI,103) DUM1,DUM2,I,DATA(I,LS+2),DATA(I,LS+3)
   24 CONTINUE
      GO TO 9
C
   14 DO 25 K=1,NREA
      READ (NI,104) DUM1,DUM2,I,(DATA(I,J),J=KS,KR)
      READ  (NI,104) DUM1,DUM2,I,(DATA(I,J),J=LS,LR)
   25 CONTINUE
      GO TO 9
C
   15 DO 26  K=1,NREA
      READ (NI,105) DUM1,DUM2,I, DATA(I,KT), DATA(I,KP)
      READ  (NI,105) DUM1,DUM2,I,DATA(I,LT),DATA(I,LP)
   26 CONTINUE
      GO TO 9
C
   16 DO 27 K=1,NREA
      READ. (NI,106) DUM1,DUM2,I,DATA(I,KS), DATA(I,KS+1) ,DATA(I,KT),DAT
     *A(I,KP)
      READ (NI, 106) DUM1,DUM2,I,DATA(I,LS),DATA(I,LS+1),DATA(I,LT),DATA
     *(I,LP)
   27 CONTINUE
      GO TO 9
C
   17 DO 28 K=1,NREA
      READ (NI,107) DUM1,DUM2,I, (DATA(I,J),J=KQ,KP)
      READ (NI,107) DUM1,DUM2,I,(DATA(I,J) ,J=LQ,LP)
   28 CONTINUE
      GO TO 9
C
   18 DO 29  K= 1,NREA
      READ (NI,108) DUM1,DUM2,I, (DATA(I,J),J=KS,KP)
      READ (NI,108) DUM1,DUM2,I,(DATA(I,J), J=LS,LP)
   29 CONTINUE
  101 FORMAT (A4)
  102 FORMAT (2A4,8X,I2,2X,2(2X,F8.0))
  103 FORMAT (2A4,8X,I2,22X,2(2X,F8.0))
  104 FORMAT (2A4,8X,I2,2X, 4(2X,F8.0))
  105 FORMAT (2A4,8X,I2,42X,2(2X,F8.0))
  106 FORMAT (2A4,8X,I2,2X, 2(2X,F8.0),20X,2(2X,F8.0))
  107 FORMAT (2A4,8X,I2,22X,4(2X,F8.0))
  108 FORMAT (2A4,8X,I2,2X,6(2X,F8.0))
C
C          RETURNS TO CALLER RSDD
C
    9 RETURN
      END
```

SUBROUTINE RDRATE

```
      SUBROUTINE RDRATE
      COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40),
     * IREAD(20), CONDE(20,2), CONDI(20,18), DATA(40,94), FINIS(40,9),
     * G(40,20,5), HWFLOW(10,12), INIT(10), IORD(20,20), MONTH(12),
     * JUNC(10,3), TITLE(20), QSCAL(5), TEMPR(40), CMAXM(40,5),
     * CMINUX(40,5), TLMAXM(40,5), XL(40), CT(40)
      COMMON EPSI(40), SEPSI(40), XACT(40,5), CMINUM(40,5), TMINUM(40),
     * CMINDM(40,5), NDOPT(40), K2OPT(40), NSOC(20,28), NSTAT(20),
     * XORD(5),YORD(5), QT(40,9), MSK(40,5), NJC(10), ICPY(10),
     * FIRST(40), STATE(40), NDAYS(40), STATE1(40), FIRST1(40)
      COMMON KONTS(40,2), NTOTS(40,2), NDAYS1(40), KOUNT(40,2), PREV(40)
     * , NTOT(40,2), PREV1(40), Q(31,20), TS(40,2), TSS(40,2), TUP(40),
     * TDOWN(40), DELTA(40), HTH(40), CMINDX(40,5), TMINUX(40),
     * TMINDX(40),TMINDM(40),X1(40,5,2),Y1(40,5),DEFC(40),TCOMP(40,2)
      COMMON CINT(10,4), TLEN(10), NSEG(20), MNPLCY(40),TL(40)
      COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JQ, JU, JX, JY,
     * JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSEAS, TA,AACUP,BBCUP,
     *CCUP1,CCUP2,CCUP3,CCUP4,CCUP5,CCUP6,CCUP7, CCRON, A3, DBENTH,
     * ELEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NI, NINIT, NOX, MZ,
     * MY, MZY, NJUNC, NTRIB, NREA, NACC, DENOM, ESYS, TOTCST, CHECK
C
C            THERE ARE EIGHT POSSIBLE COMBINATIONS OF THE THREE REACTION RATES
C            WHICH MUST BE READ ON EACH SUBFILE
      NSUM= 1
      LINIT = 3*(MY-1) + 8
      LMID = LINIT+1
      NFIN  = 3*MY + 7
C
C            ONLY THE REACTION RATES OF THE PARAMETERS TO BE SIMULATED
C            MUST BE READ
C            DETERMINE WHICH COMBINATION OF THE REACTION RATES MUST BE READ
C
      DO 750  NBAR=1,3
      NRY =  3*(MY-1) + 7 + NBAR
      NRX =  IREAD(NRY)
      IF (NRX.EQ.0 )  GO TO 750
      GO TO (1,2,3),NBAR
    1 IRZ = 1
      GO TO 4
    2 IRZ = 2
      GO TO 4
    3 IRZ = 4
    4 NSUM = NSUM + IRZ
  750 CONTINUE
      KS = LINIT +  77
      KG = LINIT +  78
      KT = LINIT +  79
C           READ THE APPROPRIATE COMBINATION OF REACTION RATES
C
      GO TO (11,12,13,14,15,16,17,18),NSUM
   11 DO 21 K=1,NREA
      READ (NI,101) BLANK1
   21 CONTINUE
      GO TO 500
C
   12 DO 23 K = 1,NREA
      READ (NI,102) DUM1,DUM2,I,DATA(K,KS)
   23 CONTINUE
      GO TO 500
   13 DO 24  K=1,NREA
      READ (NI,103) DUM1,DUM2,I,DATA(K,KG)
   24 CONTINUE
      GO TO 500
   14 DO 25  K=1,NREA
      READ (NI,104) DUM1,DUM2,I,DATA(K,KS),DATA(K,KG)
   25 CONTINUE
      GO TO 500
   15 DO 26  K=1,NREA
      READ (NI,105) DUM1,DUM2,I,DATA(K,KT)
   26 CONTINUE
      GO TO 500
C
   16 DO 27  K=1,NREA
      READ (NI,106) DUM1,DUM2,I,DATA(K,KS),DATA(K,KT)
   27 CONTINUE
      GO TO 500
   17 DO 28  K=1,NREA
      READ (NI,107)  DUM1,DUM2,I,DATA(K,KG),DATA(K,KT)
   28 CONTINUE
      GO TO 500
   18 DO 29  K=1,NREA
      READ (NI,108) DUM1,DUM2,I,(DATA(K,L),L=KS,KT)
   29 CONTINUE
  101 FORMAT (A1)
  102 FORMAT (2A4,8X,I2,      4X,F8.3)
  103 FORMAT (2A4,8X,I2,24X,      F8.0)
  104 FORMAT (2A4,8X,I2,4X,       F8.0,12X,F8.0)
  105 FORMAT (2A4,8X,I2,44X,      F8.0)
  106 FORMAT (2A4,8X,I2,4X,      F8.0 ,32X,      F8.0)
  107 FORMAT (2A4,8X,I2,24X,F8.0,12X,F8.0 )
  108 FORMAT (2A4,8X,I2,4X,F8.0,2(12X,F8.0))
  500 RETURN
      END
```

SUBROUTINE RCHAR

```
      SUHHUUTINE RCHAR
      COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40),
     * IREAD(20), CONDE(20,2), CONDI(2V,18), DATA(40,94), FINIS(40,9),
     * G(40,20,5), HWFLOW(10,12), INIT(10), IORD(20,20), MONTH(12),
     * JUNC(10,3), TITLE(20), OSCAL(5), TEMPR(40), CMAXM(40,5),
     * CMINUX(40,5), TLMAXM(40,5), XL(40), CT(40)
      COMMON EPSI(40), SEPSI(40), XACT(40,5), CMINUM(40,5), TMINUM(40),
     * CMINOM(40,5), NDOPT(40), K2OPT(40), NSOC(20,28), NSTAT(20),
     * XORD(5),YORD(5), OT(40,9), MSK(40,5), NJC(10), ICPY(10),
     * FIRST(40), STATE(40), NDAYS(40), STATE1(40), FIRST1(40)
      COMMON KONTS(40,2), NTOTS(40,2), NDAYS1(40), KOUNT(40,2), PREV(40)
     * , NTOT(40,2), PREV1(40), Q(31,20), TS(40,2), TSS(40,2), TUP(40),
     * TDOWN(40), DELTA(40), HTM(40), CMINOX(40,5), TMINUX(40),
     * TMINOX(40),TMINOM(40),X1(40,5,2),Y1(40,5),DEFC(40),TCOMP(40,2)
      COMMON CINT(10,4), TLEN(10), NSEG(20), MNPLCY(40),TL(40)
      COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JQ, JU, JX, JY,
     * JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSEAS, TA,AACUP,BBCUP,
     *CCUP1,CCUP2,CCUP3,CCUP4,CCUP5,CCUP6,CCUP7, CCROM, A3, DHENTH,
     * FLEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NI, NINIT, NOX, MZ,
     * MY, MZY, NJUNC, NTRIM, NMEA, NACC, DENOM, ESYS, TOTCST, CHECK
      COMMON/BLK/MASK(40)
      COMMON/BLOCK2/TIME,NMR,DTYPE,POPT
      LOGICAL IMPL,MASK,TEST, MNPLCY,POPT
      DATA END/4HEND /
      IF (POPT) WRITE (NJ,100) NUM
  100 FORMAT (1H1,//10X,*PARAMETER NUMBER = *,I3,//10X,*REACH NO. IMPL.
     *  MN. PLCY.    CT       DELTA    IMPL. LOC.    EPSI       SEPSI     TUP
     *   TDOWN*,//)
      DO 50 I = 1,NMEA
      READ (NI,500) DUM1,DUM2,TEST,MNPLCY(I),CT(I),DELTA(I),XL(I),EPSI(I
     *), SEPSI(I),TUP(I),TDOWN(I)
  500 FORMAT (2A4,2L1,7F10.0)
      IF (POPT) WRITE (NJ,200) I,TEST,MNPLCY(I),CT(I),DELTA(I),XL(I),
     *EPSI(I),SEPSI(I),TUP(I),TDOWN(I)
  200 FORMAT (/13X,I3,5X,L1,9X,L1,4X,F8.3,2X,F6.2,4X,F6.2,4X,F7.3,2X,F7.
     *3,2X,F6.2,2X,F6.2)
      IF (TEST) IMPL(I) = IMPL(I).OR.MASK(NUM)
   50 CONTINUE
      READ (NI,300) DUM1
  300 FORMAT (A4)
      IF (DUM1.NE.END) GO TO 400
      RETURN
  400 STOP 401
      END
```

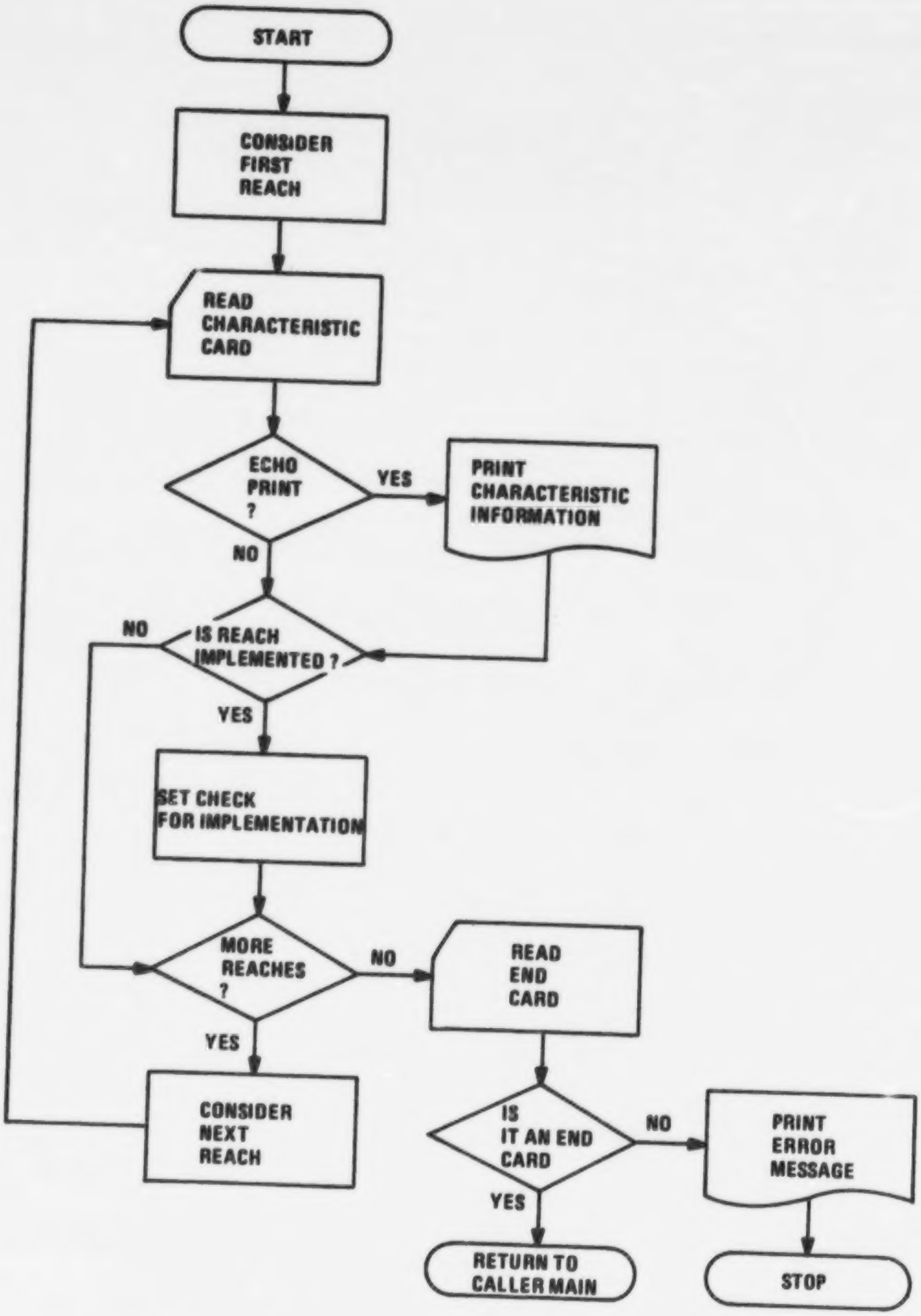

START
CONSIDER FIRST REACH
READ CHARACTERISTIC CARD
ECHO PRINT ?
YES
PRINT CHARACTERISTIC INFORMATION
NO
NO
IS REACH IMPLEMENTED ?
YES
SET CHECK FOR IMPLEMENTATION
MORE REACHES ?
NO
READ END CARD
YES
CONSIDER NEXT REACH
IS IT AN END CARD
NO
PRINT ERROR MESSAGE
YES
RETURN TO CALLER MAIN
STOP

Figure 77. Flowchart for Subroutine RCHAR

SUBROUTINE QTCAL

```
      SUBROUTINE QTCAL
      COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40),
     * IREAD(20), CONDE(20,2), CONDI(20,18), DATA(40,94), FINIS(40,9),
     * G(40,20,5), HWFLOW(10,12), INIT(10), IORD(20,20), MONTH(12),
     * JUNC(10,3), TITLE(20), QSCAL(5), TEMPR(40), CMAXM(40,5),
     * CMINUX(40,5), TLMAXM(40,5), XL(40), CT(40)
      COMMON EPSI(40), SEPSI(40), XACT(40,5), CMINUM(40,5), TMINUM(40),
     * CMINDM(40,5), NDOPT(40), K2OPT(40), NSOC(20,28), NSTAT(20),
     * XORD(5),YORD(5), QT(40,9), MSK(40,5), NJC(10), ICPY(10),
     * FIRST(40), STATE(40), NDAYS(40), STATE1(40), FIRST1(40)
      COMMON KONTS(40,2), NTOTS(40,2), NDAYS1(40), KOUNT(40,2), PREV(40)
     * , NTOT(40,2), PREV1(40), Q(31,20), TS(40,2), TSS(40,2), TUP(40),
     * TDOWN(40), DELTA(40), HTH(40), CMINDX(40,5), TMINUX(40),
     * TMINDX(40),TMINDM(40),X1(40,5,2),Y1(40,5),DEFC(40),TCOMP(40,2)
      COMMON CINT(10,4), TLEN(10), NSEG(20), MNPLCY(40),TL(40)
      COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JQ, JU, JX, JY,
     * JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSEAS, TA,AACUP,BBCUP,
     *CCUP1,CCUP2,CCUP3,CCUP4,CCUP5,CCUP6,CCUP7, CCRON, A3, DBENTH,
     * ELEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NI, NINIT, NOX, MZ,
     * MY, MZY, NJUNC, NTRIB, NREA, NACC, DENOM, ESYS, TOTCST, CHECK
      COMMON/BLK/MASK(40)
      COMMON/BLK4/ X(5),Y(5),DY(5),A(6),B(6),C(6),D(6),WK(50)
      LOGICAL CACT,IMPL,MASK,CHECK
      DATA END/5HEND  /
C                                                                        20
C                                                                        40
      DO 585 I = 1,NREA
      IF (CHECK.AND.MASK(I)) 585,595
  585 CONTINUE
C
   44 DO 13 IRUN=1,NR
      DO 24 L = 1, 10
      CONDI(L,18)=HWFLOW(L,NSEAS)
C
C            IF FLOW SENSITIVITY ANALYSIS IS SPECIFIED, MULTIPLY HEADWATER
C            - FLOWS BY THE FLOW SCALING FACTOR
      CONDI(L,18) = QSCAL(IRUN) * CONDI(L,18)
   24 CONTINUE                                                         2650
C                                                                      1730
      CALL REINI
      IF (NUM.GE.14) GO TO 13
C                                                                      2860
C            REPEAT FOR ALL SIMULATIONS
      DO 8740 IS=1,NREA
      X1(IS,IRUN,1) = G(IS,NUM,IRUN)
      X1(IS,IRUN,2) = FINIS(IS,9)
      Y1(IS,IRUN) = FINIS(IS,4)
 8740 CONTINUE
   13 CONTINUE
      IF (IREAD(NUM).EQ.1) GO TO 597
C            REPEAT FOR ALL PARAMETERS
      IF (NUM.NE.17) GO TO 9202
      DO 9203 IS = 1,NREA
      CSAT = (14.62 -(.3898*TEMPR(IS)) + (.006969*TEMPR(IS)**2) - ( .000
     *05897 * TEMPR(IS)**3)) * ((1.0 - (0.00000697*ELEV)) ** 5.167)
 9203 CT(IS) = CSAT - CT(IS)
 9202 DO 8900 IM = 1,9
      DO 8741 IR=1,NREA
      DO 8800 IRUN = 1,NR
      Y(IRUN) = Y1(IR,IRUN)
      IT = IM - 3
```

```
C  INSERT APPROPRIATE VALUES IN X ARRAY
      IF (NUM.GE.14) GO TO 8801
      IF (IM.GT.3) GO TO 8900
      GO TO (911,912,913),IM
  911 X(IRUN) =  X1(IR,IRUN,1)
      GO TO 8800
  912 X(IRUN) =  X1(IR,IRUN,2)
      GO TO 8800
  913 IF (IMPL(IR).AND.MASK(NUM)) 941,8741
  941 X(IRUN) = XACT(IR,IRUN)
      GO TO 8800
 8801 IF (IM.LE.3) GO TO 8900
      GO TO (961,962,963,964,965,966),IT
  961 X(IRUN) = CMAXM(IR,IRUN)
      GO TO 8800
  962 X(IRUN) = CMINUM(IR,IRUN)
      GO TO 8800
  963 X(IRUN) = CMINDM(IR,IRUN)
      GO TO 8800
  964 IF (IMPL(IR).AND.MASK(NUM)) 984,8741
  984 X(IRUN) = XACT(IR,IRUN)
      GO TO 8800
  965 IF (IMPL(IR).AND.MASK(NUM)) 985,8741
  985 X(IRUN) = CMINUX(IR,IRUN)
      GO TO 8800
  966 IF (IMPL(IR).AND.MASK(NUM)) 986,8741
  986 X(IRUN) = CMINDX(IR,IRUN)
 8800 CONTINUE
C  ARRANGE X ARRAY IN INCREASING ORDER
      XORD(1) = X(1)
      NG = 1
      NX = NR
  901 DO 900 I= 1,NX
      IF (X(I).GT.XORD(NG)) GO TO 900
      XORD(NG) = X(I)
      YORD(NG)=Y(I)
      NZ = I
  900 CONTINUE
      NG = NG + 1
      IF (NX.NE.NZ) Y(NZ) = Y(NX)
      IF (NX.NE.NZ) X(NZ) = X(NX)
      XORD(NG) = X(1)
      YORD(NG) = Y(1)
      NX = NX - 1
      IF (NG.LT.NR) GO TO 901
C
      DO 902 I= 1,NR
      X(I) = XORD(I)
  902 Y(I) = YORD(I)
      CNUM = CT(IR)
      IF (X(1).GT.CNUM) 8744,8743
 8744 QT(IR,IM) = 5.E+06
      IF (IM.NE.4) GO TO 8741
C
C  IF CONCENTRATION EXCEEDS THRESHOLD FOR ALL FLOW DESIGNS, DETERMINE
C  LOCATION WITHIN THE REACH AT WHICH CONCENTRATION IS NEAREST THRESHOLD
C
      CNT1 = CMAXM(IR,1)-CT(IR)
      TL(IR) = TLMAXM(IR,1)
      DO 8751 IX=2,NR
      CNT2 = CMAXM(IR,IX)-CT(IR)
      IF (CNT2.GT.CNT1) GO TO 8751
      CNT1 = CNT2
      TL(IR) = TLMAXM(IR,IX)
 8751 CONTINUE
      GO TO 8741
```

```
C  DETERMINE WHICH FLOW INTERVAL  THE THRESHOLD CONCENTRATION LIES IN
 8743 DO 8720 IRUN = 2,NR
      IF (X(IRUN).LT.CNUM) GO TO 8720
      IF (IM.EQ.4) TL(IR) = TLMAXM(IR,IKUN)
      MZ = IRUN
      XX = X(IRUN-1)
      GO TO 8722
 8720 CONTINUE
      GO TO 8721
C
C  INTERPOLATE VALUE OF THRESHOLD FLOW IN THIS INTERVAL USING CUBIC
C  SPLINE METHOD
C
 8722 S=0.
      N=NR
      DO 3010 IK=1,5
      DY(IK)=1.
 3010 CONTINUE
      IF (X(1).EQ.0.) GO TO 410
      GO TO 420
  410 DO 430 IX=2,NR
      JX=IX
      IF (X(IX).GT.0.) GO TO 450
  430 CONTINUE
      GO TO 8721
  450 N = NR -JX + 2
      JX = NR-N+1
      DO 460 IX=1,N
      X(IX) = X(JX)
      JX = JX + 1
  460 CONTINUE
      MZ = MZ-(NR-N)
  420 CALL ICSSMU(S,N)
      XBAR = CNUM - XX
      QT(IR,    IM) = ((D(MZ) * XBAR + C(MZ)) *  XBAR + B(MZ))  * XBAR +
     *A(MZ)
      DO 8905 J = 1,20
      IF (NSTAT(J).EQ.0) GO TO 8905
      NGS = J
      DO 598 JJ = 1,28
      IF (NSOC(NGS,JJ).EQ.IR) 5598,5599
 5599 IF (NSOC(NGS,JJ).EQ.0) GO TO 8905
  598 CONTINUE
 8905 CONTINUE
 5598 MZZ = NSEG(NGS)
      ARAT      =FINIS(IR,4)/FINIS(MZZ,4)
 8200 QT  (IR,    IM) = (1./ARAT    ) * QT(IR,    IM)
      GO TO 8741
 8721 QT  (IR,    IM) = -1.
      IF (IM.NE.4) GO TO 8741
C
C  IF CONCENTRATION DOES NOT EXCEED THRESHOLD IN ANY FLOW DESIGN,
C  DETERMINE LOCATION WITHIN THE  REACH IN WHICH CONCENTRATION COMES
C  NEAREST THE THRESHOLD
C
      CNT1 = CT(IR)-CMAXM(IR,1)
      TL(IR) = TLMAXM(IR,1)
      DO 8750  IX = 2,NR
      CNT2 = CT(IR) - CMAXM(IR,IX)
      IF (CNT2.GT.CNT1) GO TO 8750
      CNT1 = CNT2
      TL(IR) = TLMAXM(IR,IX)
 8750 CONTINUE
 8741 CONTINUE
 8900 CONTINUE
      GO TO 597
  595 WRITE (NJ,596)
  596 FORMAT (1X,60HEACH SEGMENT HAS NOT BEEN ASSOCIATED WITH A GAUGING
     * STATION
      STOP 441
C
  597 RETURN
      END
```

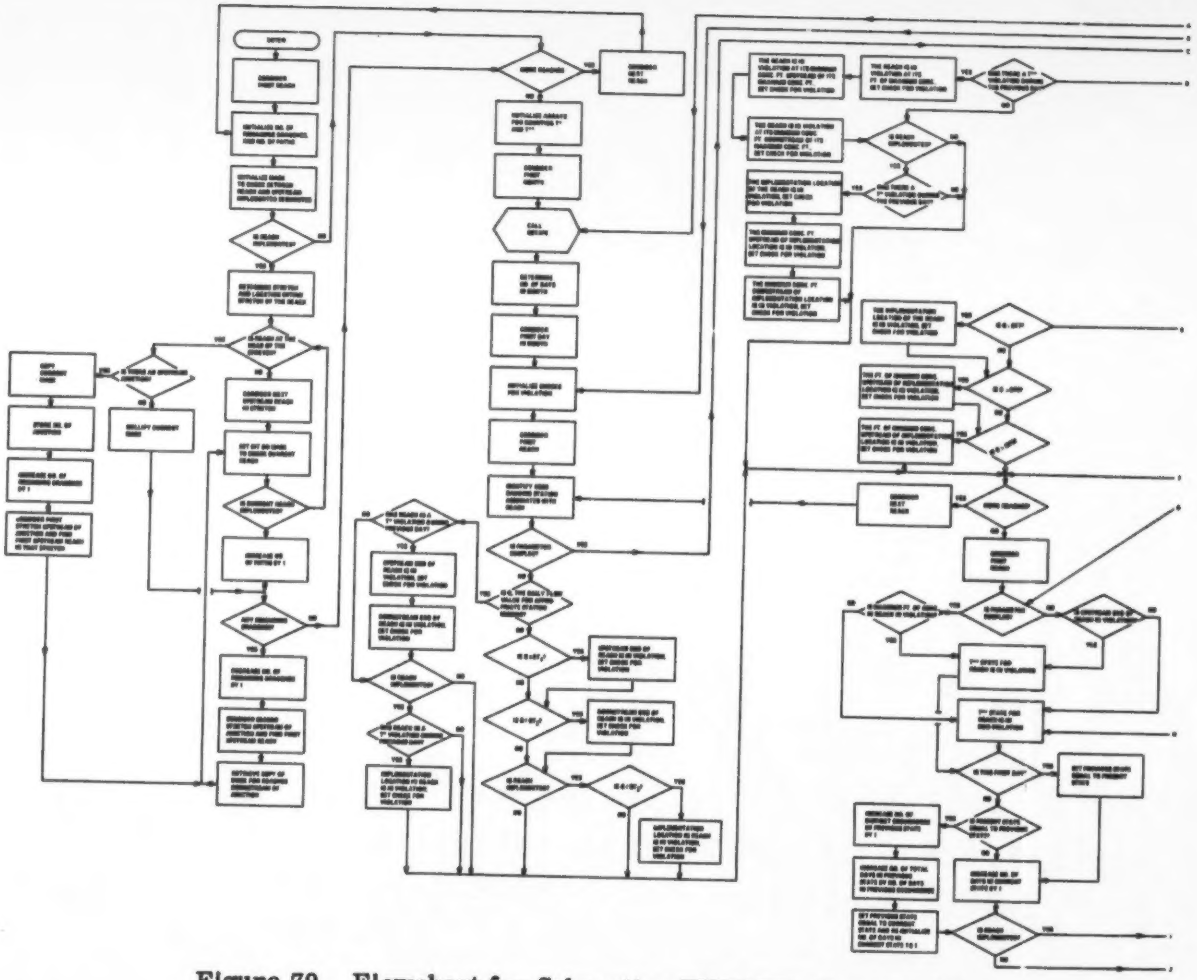


Figure 79. Flowchart for Subroutine EXPDUR (Sheet 1 of 2)

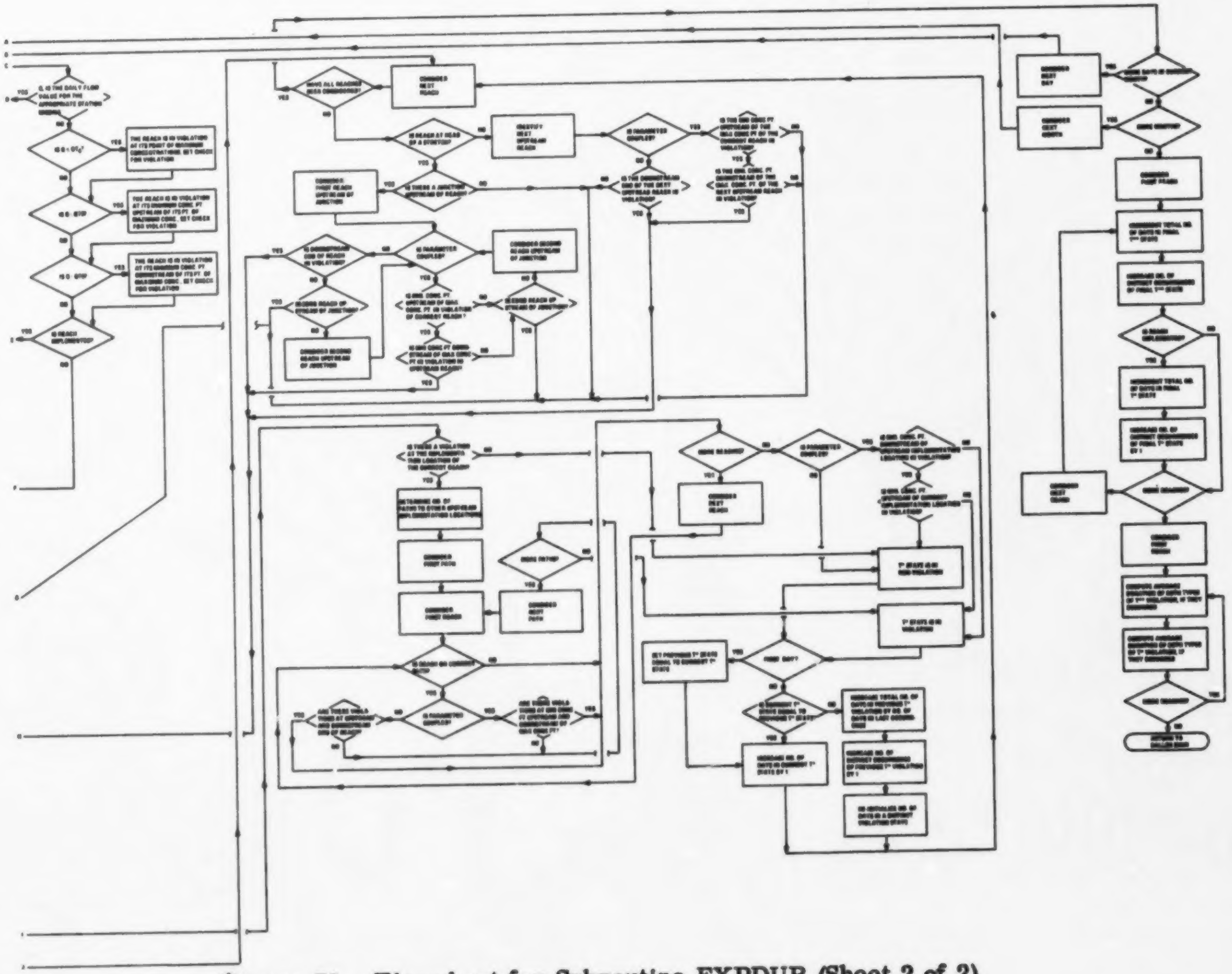


Figure 79. Flowchart for Subroutine EXPDUR (Sheet 2 of 2)

SUBROUTINE REINI

```
      SUBROUTINE REINI
      COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40),
     * IREAD(20), CONDE(20,2), CONDI(20,18), DATA(40,94), FINIS(40,9),
     * G(40,20,5), HWFLOW(10,12), INIT(10), IORD(20,20), MONTH(12),
     * JUNC(10,3), TITLE(20), QSCAL(5), TEMPR(40), CMAXM(40,5),
     * CMINUX(40,5), TLMAXM(40,5), XL(40), CT(40)
      COMMON EPSI(40), SEPSI(40), XACT(40,5), CMINUM(40,5), TMINUM(40),
     * CMINDM(40,5), NDOPT(40), K2OPT(40), NSOC(20,28), NSTAT(20),
     * XORD(5),YORD(5), QT(40,9), MSK(40,5), NJC(10), ICPY(10),
     * FIRST(40), STATE(40), NDAYS(40), STATE1(40), FIRST1(40)
      COMMON KONTS(40,2), NTOTS(40,2), NDAYS1(40), KOUNT(40,2), PREV(40)
     * , NTOT(40,2), PREV1(40), Q(31,20), TS(40,2), TSS(40,2), TUP(40),
     * TDOWN(40), DELTA(40), HTH(40), CMINDX(40,5), TMINUX(40),
     * TMINDX(40),TMINDM(40),X1(40,5,2),Y1(40,5),DEFC(40),TCOMP(40,2)
      COMMON CINT(10,4), TLEN(10), NSEG(20), MNPLCY(40),TL(40)
      COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JQ, JU, JX, JY,
     * JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSEAS, TA,AACUP,BBCUP,
     *CCUP1,CCUP2,CCUP3,CCUP4,CCUP5,CCUP6,CCUP7, CCRON, A3, DBENTH,
     * ELEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NI, NINIT, NOX, MZ,
     * MY, MZY, NJUNC, NTRIB, NREA, NACC, DENOM, ESYS, TOTCST, CHECK
C
      DO 1 I=1,NINIT
      JA=INIT(I)
C
C
      FINL = CONDI(JA,NUM)
      QUP   =CONDI(JA,18)
C
C
      CALL TRIBD                                 CALL  T R I B D
C
C
C                                                SET FINAL CONDITIONS TO
C                                                CALCULATED CONDITIONS
      CONDI(JA,18) = CONDI(JA,18) /QSCAL(IRUN)
      CONDE (JA,1)    = FINIS(IA, 9)
      CONDE(JA,2) = QUP
C
C           REPEAT FOR ALL HEADWATER STRETCHES
C
    1 CONTINUE
C
      IF (NJUNC.EQ.0) GO TO 5
      CALL RMATC
C
    5 RETURN
      END
```

SUBROUTINE TRIBD

```
      SUBROUTINE TRIBD                                                  6220
      COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40),
     * IREAD(20), CONDE(20,2), CONDI(20,18), DATA(40,94), FINIS(40,9),
     * G(40,20,5), HWFLOW(10,12), INIT(10), IORD(20,20), MONTH(12),
     * JUNC(10,3), TITLE(20), QSCAL(5), TEMPR(40), CMAXM(40,5),
     * CMINUX(40,5), TLMAXM(40,5), XL(40), CT(40)
      COMMON EPSI(40), SEPSI(40), XACT(40,5), CMINUM(40,5), TMINUM(40),
     * CMINDM(40,5), NDOPT(40), K2OPT(40), NSOC(20,20), NSTAT(20),
     * XORD(5),YORD(5), QT(40,9), MSK(40,5), NJC(10), ICPY(10),
     * FIRST(40), STATE(40), NDAYS(40), STATE1(40), FIRST1(40)
      COMMON KONTS(40,2), NTOTS(40,2), NDAYS1(40), KOUNT(40,2), PREV(40)
     * , NTOT(40,2), PREV1(40), Q(31,20), TS(40,2), TSS(40,2), TUP(40),
     * TDOWN(40), DELTA(40), HTH(40), CMINDX(40,5), TMINUX(40),
     * TMINDX(40),TMINDM(40),X1(40,5,2),Y1(40,5),DEFC(40),TCOMP(40,2)
      COMMON CINT(10,4), TLEN(10), NSEG(20), MNPLCY(40),TL(40)
      COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JQ, JU, JX, JY,
     * JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSFAS, TA,AACUP,BBCUP,
     *CCUP1,CCUP2,CCUP3,CCUP4,CCUP5,CCUP6,CCUP7, CCRON, A3, DBENTH,
     * ELEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NI, NINIT, NOX, MZ,
     * MY, MZY, NJUNC, NTRIB, NREA, NACC, DENOM, ESYS, TOTCST, CHECK
      COMMON/BLK/MASK(40)
      LOGICAL CACT ,IMPL,MASK
                                                                        6320
C                                                                       6370
C
      I=1
      KP = 0
C           COMPUTE SUBSCRIPTS OF EFFLUENT CONCENTRATIONS
C
      KPP = 0
      IF (NUM.GE.16) KPP=2
      KP = (NUM-1)/3
      JY = 15 + 2*NUM + 6*KP
      JX = 8 + NUM
      JQ  = JY + 1
      JB = 21 + 2*NUM + 6*KP - KPP
      JD =JB + 1
                                                                        6400
C
    2 IF (IORD(JA,I)) 1,1,3
                                                                        6440
C
3     IA=IORD(JA,I)
C
      CACT = .FALSE.
                                                                        6460
C
C
C           ***  COMPUTE PHYSICAL PARAMETERS FOR EACH REACH ***
C  MULTIPLY TRIBUTARY AND MUNICIPAL FLOWS BY FLOW SCALING FACTOR
C
      DATA(IA,7) = QSCAL(IRUN) * DATA(IA,7)
      DATA(IA,5) = QSCAL(IRUN) * DATA(IA,5)
C
C           STREAM FLOW IS AUGMENTED BY TRIBUTARY AND MUNICIPAL FLOW
      FINIS(IA,4) = QUP + DATA(IA,5) + DATA(IA,7)
      FINIS(IA,1) = IA
      FINIS(IA,2) = DATA(IA,2)
      FINIS(IA,3) = DATA(IA,1)
C
```

```
C           VELOCITY IS COMPUTED AS A FUNCTION OF FLOW
      FINIS(IA,7) = DATA(IA,3) * (FINIS(IA,4) ** DATA(IA,4))
      FINIS(IA,6) = DATA(IA,1)/ (FINIS(IA,7)*16.36)
      FINIS(IA,8) = DATA(IA,14)
      FINIS(IA,5) = 0.
C
C                                                                       6510
      COMP = FINL
      IF (NUM.NE.17) GO TO 3374
C
C           IF DO IS THE PARAMETER, DETERMINE THE REAERATION COEFFICIENT
      CALL K2CAL
C
C           CONCENTRATION OF INDUSTRIAL SOURCES EQUALS THE AMBIENT STREAM
C           CONCENTRATION PLUS THE NET CHANGE DUE TO INDUSTRY
 3374 DCONC = COMP + DATA(IA,JQ)
      UNACC = 0.
C
C           COMPUTE THE MASS ADDED AT THE HEAD OF THE REACH
      DELTAM = DCONC * DATA(IA,6) + DATA(IA,JY) * DATA(IA,5) + DATA(IA,J
     *B) * DATA(IA,7) + UNACC
      DELTAQ = DATA(IA,5) + DATA(IA,7)
      QINT   = DATA(IA,6)
C
C           COMPUTE THE CONCENTRATION OF THE PARAMETER AT THE HEAD OF A
C           REACH AFTER THE MASS FROM THE SOURCES HAS BEEN ADDED
  114 G(IA,NUM,IRUN) = (COMP*(QUP-QINT) + DELTAM) / (QUP+DELTAQ)
      IF (IMPL(IA).AND.MASK(NUM)) CACT = .TRUE.
C
C           IF PARAMETER IS CONSERVATIVE, BEGINNING CONC = FINAL CONC.
C           WITHIN THE REACH
C
      IF (NVAR(JU).LE.7) FINIS(IA,9) = G(IA,NUM,IRUN)
      IF (NVAR(JU).LE.7) GO TO 333
      NZ = 77 + NUM
C
      IF (NVAR(JU).LE.13) GO TO 34
C
C           IF PARAMETER IS NON-CONSERVATIVE COUPLED, COMPUTE THE CONCENTRATION
C           - OF EACH PARAMETER ACCORDING TO ITS OWN UNIQUE EQUATION
C
   35 CALL COUPLES
      GO TO 33
C
C           IF THE PARAMETER IS NON-CONSERVATIVE NON-COUPLED, COMPUTE
C           THE DECAY WITHIN THE REACH
   34 CALL DECAY
      GO TO 33
  333 IF (CACT) XACT(IA,IRUN) =  G(IA,NUM,IRUN)
C
C
C           SET FINAL CONCENTRATION OF PARAMETER IN REACH, EQUAL TO
C           - NON-SUBSCRIPTED VARIABLE
C
   33 FINL = FINIS(IA,9)
C
      QUP = FINIS (IA,4)
C
      I = I + 1
                  DATA(IA,5) = DATA(IA,5) / QSCAL(IRUN)
                  DATA(IA,7) = DATA(IA,7) / QSCAL(IRUN)
      GO TO 2
    1 RETURN
      END
                                                                        6810
```

SUBROUTINE COUPLES

```
      SUBROUTINE COUPLES
      COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40),
     * IREAD(20), CONDE(20,2), CONDI(20,18), DATA(40,94), FINIS(40,9),
     * G(40,20,5), HWFLOW(10,12), INIT(10), IORD(20,20), MONTH(12),
     * JUNC(10,3), TITLE(20), QSCAL(5), TEMPR(40), CMAXM(40,5),
     * CMINUX(40,5), TLMAXM(40,5), XL(40), CT(40)
      COMMON EPSI(40), SEPSI(40), KACT(40,5), CMINUM(40,5), TMINUM(40),
     * CMINDM(40,5), NDOPT(40), K2OPT(40), NSOC(20,28), NSTAT(20),
     * XORD(5),YORD(5), QT(40,9), MSK(40,5), NJC(10), ICPY(10),
     * FIRST(40), STATE(40), NDAYS(40), STATF1(40), FIRST1(40)
      COMMON KONTS(40,2), NTOTS(40,2), NDAYS1(40), KOUNT(40,2), PREV(40)
     * , NTOT(40,2), PREV1(40), Q(31,20), TS(40,2), TSS(40,2), TUP(40),
     * TDOWN(40), DELTA(40), HTH(40), CMINDX(40,5), TMINUX(40),
     * TMINDX(40),TMINDM(40),X1(40,5,2),Y1(40,5),DEFC(40),TCOMP(40,2)
      COMMON CINT(10,4), TLEN(10), NSEG(20), MNPLCY(40),TL(40)
      COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JQ, JU, JX, JY,
     * JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSFAS, TA,AACUP,BBCUP,
     *CCUP1,CCUP2,CCUP3,CCUP4,CCUP5,CCUP6,CCUP7, CCRON, A3, DBENTH,
     * ELEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NI, NINIT, NOX, MZ,
     * MY, MZY, NJUNC, NTRIH, NREA, NACC, DENOM, ESYS, TOTCST, CHECK
      COMMON/REACT/FACT(20)
      LOGICAL CACT
C
      NOX = NUM - 13
      DATA(IA,NZ) = DATA(IA,NZ) *FACT(NUM) **(TEMPR(IA)-20.)
C
C           COMPUTE FACTORS OF SOLUTION FOR PARAMETER IN CONCERN
C
      GO TO (1,2,3,4),NOX
    1 ACUP     =AACUP
      ACUP     =ACUP     *1.20**(TEMPR(IA)-20.)
      A14 = ACUP * G(IA,9,IRUN)/ (DATA(IA,86)-DATA(IA,91))
      GO TO 777
    2 BCUP     =BBCUP
      A15 = -BCUP * A14  /  (DATA(IA,86) - DATA(IA,92))
      A16 = BCUP * (G(IA,14) + A14) / (DATA(IA,91) - DATA(IA,92))
      GO TO 777
    3 CUP5     =CCUP5
      CUP5     =CUP5     *1.07**(TEMPR(IA)-20.)
      CUP6     =CCUP6
      CUP6     =CUP6     *1.07**(TEMPR(IA)-20.)
      AA = (-CUP5* A15)/(DATA(IA,86) - DATA(IA,93))
      AB = (-CUP5*A16) / (DATA(IA,91) - DATA(IA,93))
      XX = DATA (IA,92) -DATA(IA,93)
      IF (XX.EQ.0.) GO TO 22
      AC = CUP5 *(G(IA,15,IRUN)+A16+A15)/(DATA(IA,92)-DATA(IA,93))
      GO TO 23
   22 AC = 0.
   23 CONTINUE
      AD = CUP6 * G(IA,8,IRUN) / (DATA(IA,85) - DATA(IA,93))
      GO TO 777
C
C
    4 CUP1     =CCUP1
      CUP1     =CUP1     *1.07**(TEMPR(IA)-20.)
      CIRON     =CCRON
          CIRON     =CIRON     *1.07**(TEMPR(IA)-20.)
      CUP2     =CCUP2
      CUP2     =CUP2     *1.047**(TEMPR(IA)-20.)
      CUP3     =CCUP3
      CUP3     =CUP3     *1.06**(TEMPR(IA)-20.)
      CUP4     =CCUP4
      CUP4     =CUP4     *1.30**(TEMPR(IA)-20.)
      CUP7     =CCUP7
      CUP7     =CUP7     *1.07**(TEMPR(IA)-20.)
      CSAT = (14.62 - (.3898* TEMPR(IA)) + (.006969*TEMPR(IA)**2) -(.000
     *05897 * TEMPR(IA)**3)) *((1.0  -  (0.00000697*ELEV)) ** 5.167)
      FINIS(IA,5) = CSAT
      DEFC(IA) = CSAT - G(IA,17,IRUN)
      IF (HTH(IA).EQ.0.) GO TO 300
      DEFC(IA)  = DEFC(IA)  / (1. +(.11 * (1. + .046*TEMPR(IA)) *HTH(IA)
     *))
```

```
  300 CONTINUE
      A3 = A3/100.
      A17 = A3*CUP1*G(IA,3,IRUN) /(CIRUN-DATA(IA,94))
      A18 = CUP2* G(IA,12,IRUN) / (DATA(IA,89)-DATA(IA,94))
      A19 = CUP7* (G(IA,16,IRUN)+AC+AB*AA) /(DATA(IA,93)-DATA(IA,94))
      A20 = -CUP7 * AC / (DATA(IA,92) -DATA(IA,94))
      A21 = CUP3* (G(IA,14,IRUN)+A14) / (DATA(IA,91)-DATA(IA,94))
      A22 = (CUP4*G(IA,9,IRUN)-A14*CUP3) / (DATA(IA,86)-DATA(IA,94))
      A23 = -CUP7 * AD / (DATA(IA,85) -DATA(IA,94))
      BENTH  = DBENTH / DATA(IA,94)
  777 CONTINUE
C
C
C             DIVIDE REACH INTO TEN SUBREACHES OF EQUAL DISTANCE
C             - AND TIME OF TRAVEL
C             COMPUTE SUBREACH CONCENTRATION OF PARAMETER IN CONCERN
C             - ACCORDING TO ITS OWN UNIQUE SOLUTION
C
      DO 30 N= 1,10
      TT = N
      TLEN(N)= FINIS(IA,2)- (TT*FINIS(IA,3)/10.)
      TB = TT * FINIS(IA,6) / 10.
C
      GO TO(5,6,7,8),NOX
    5 CINT(N,1)=(G(IA,14,IRUN)+A14)*EXP(-DATA(IA,91)*TB)-A14*EXP(-DATA(
     *IA,86) * TB)
      GO TO 30
    6 CINT(N,2) = (G(IA,15,IRUN)+A15+A16)*EXP(-DATA(IA,92)*TB) -A16*
     *EXP(-DATA(IA,91)*TB) - A15 * EXP(-DATA(IA,86)* TB )
      GO TO 30
    7 CINT(N,3) = (G(IA,16,IRUN)+AD+AC+AB+AA) * EXP(-DATA(IA,93)*TB)
     * -AC * EXP(DATA(IA,93)*TB) - AB * EXP( DATA(IA,92) *TB) -AB*EXP(-D
     *ATA( IA,92)*TB) -AB * EXP(-DATA(IA,91)*TB) -AA *EXP(-DATA(IA,86)*T
     *B) - AD*EXP(-DATA(IA,85)*TB)
      GO TO 30
    8 CINT(N,4)=(DEFC(IA)+A17+A22+A21+A20+A19+A18+A23-BENTH)*EXP(-DATA(
     *IA,94)*TB) - A17 * EXP(-CIRON*TB) - A22 * EXP(-DATA(IA,86)*TB) -
     *A21 * EXP(-DATA(IA,91)*TB) -A18*EXP(-DATA(IA,89)*TB) - A19 *EXP(-
     *DATA(IA,93)*TB) - A20*EXP(-DATA(IA,92)*TB) -A23*EXP(-DATA(IA,85)*T
     *B) + BENTH
      IF (N.EQ.10) FINIS(IA,9) = CSAT - CINT(10,4)
   30 CONTINUE
C
      CINIT = G(IA,NUM,IRUN)
      IF (NUM.EQ.17) CINIT=DEFC(IA)
C
C  FIND MAXIMUM CONCENTRATION AND ITS LOCATION
      MCSEG = 1
      CMAX = CINT(1,NOX)
      TLMAX = TLEN(1)
      DO 11 M = 2,10
      IF (CMAX-CINT(M,NOX)) 14,14,11
   14 CMAX = CINT(M,NOX)
      TLMAX = TLEN(M)
      MCSEG=M
   11 CONTINUE
      CMAXM(IA ,IRUN)= CMAX
      TLMAXM(IA,IRUN) = TLMAX
C  FIND MINIMUM CONCENTRATION UPSTREAM OF MAXIMUM CONCENTRATION
      CMINUM(IA,IRUN) = CMAXM(IA,IRUN)
      TMINUM(IA)      = TLMAXM(IA,IRUN)
      IF (MCSEG.LE.1) GO TO 402
      MCT = MCSEG - 1
      DO 15 I = 1,MCT
      IF (CINT(I,NOX)- CMINUM(IA,IRUN)) 16,16,15
   16 CMINUM(IA,IRUN) = CINT(I,NOX)
      TMINUM(IA)      = TLEN(I)
   15 CONTINUE
  402 IF (CMINUM(IA,IRUN).GE.CINIT)    401,400
  401 CMINUM(IA,IRUN) = CINIT
      TMINUM(IA)      = FINIS(IA,2)
```

```
C FIND MINIMUM CONCENTRATION DOWNSTREAM OF MAXIMUM CONCENTRATION
  400 CMINDM(IA,IRUN) = CMAXM(IA,IRUN)
      TMINDM(IA)      = TLMAXM(IA,IRUN)
      IF (MCSEG.EQ.10) GO TO 19
      MCT = MCSEG+1
      DO 17 I = MCT    ,10
      IF (CINT(I,NOX) - CMINDM(IA,IRUN)) 18,18,17
   18 CMINDM(IA,IRUN) = CINT(I,NOX)
      TMINDM(IA)      = TLEN(I)
   17 CONTINUE
   19 IF (CACT) 20,40
   20 TB = (FINIS(IA,2)-XL(IA))/(FINIS(IA,7)*16.36)
      GO TO (105,106,107,108),NOX
  105 XACT(IA,IRUN) = (G(IA,14,IRUN)+A14)*EXP(-DATA(IA,91)*TB)-A14*EXP(-
     *DATA(IA,86)*TB)
      GO TO 130
  106 XACT(IA,IRUN)=(G(IA,15,IRUN)+A15+A16)*EXP(-DATA(IA,92)*TB)-A16*
     *EXP(-DATA(IA,91)*TB) -A15*EXP(DATA(IA,86) *TB)
      GO TO 130
  107 XACT(IA,IRUN)=(G(IA,16,IRUN)+AD+AC+AB+AA)*EXP(-DATA(IA,93)*TB)
     * -AC * EXP(DATA(IA,93)*TB) - AB * EXP( DATA(IA,92) *TB) -AB*EXP(-D
     *ATA( IA,92)*TB) -AB * EXP(-DATA(IA,91)*TB) -AA *EXP(-DATA(IA,86)*T
     *B) - AD*EXP(-DATA(IA,85)*TB)
      GO TO 130
  108 XACT(IA,IRUN)=(DEFC(IA)+A17+A22+A21+A20+A19+A18+A23-BENTH)*EXP(-DA
     *TA(IA,94)*TB)-A17*EXP(-CIRON*TB)-A22*EXP(-DATA(IA,86)*TB) -
     *A21 * EXP(-DATA(IA,91)*TB) -A18*EXP(-DATA(IA,89)*TB) - A19 *EXP(-
     *DATA(IA,93)*TB) - A20*EXP(-DATA(IA,92)*TB) -A23*EXP(-DATA(IA,85)*T
     *B) + BENTH
  130 CONTINUE
C  FIND SUBINTERVAL WHICH C(X) IS LOCATED
      DO 39 M=1,10
      IF (XL(IA).GT.TLEN(M)) GO TO 39
      MXSEG = M
      GO TO 31
   39 CONTINUE
      MXSEG = 0
      CMINUX(IA,IRUN) = CINIT
      TMINUX(IA) = FINIS(IA,2)
      GO TO 34
C  FIND MINIMUM CONCENTRATION UPSTREAM OF X
   31 CMINUX(IA,IRUN) = G(IA,NUM,IRUN)
      TMINUX(IA)      = FINIS(IA,2)
      MCT = MXSEG
      DO 32 I = 1,MCT
      IF (CINT(I,NOX)-CMINUX(IA,IRUN)) 33,33,32
   33 CMINUX(IA,IRUN) = CINT(I,NOX)
      TMINUX(IA)      = TLEN(I)
   32 CONTINUE
   37 IF (CMINUX(IA,IRUN).GE.CINIT) 38,34
   38 CMINUX(IA,IRUN) = CINIT
      TMINUX(IA)      = FINIS(IA,2)
C  FIN MINIMUM CONCENTRATION DOWNSTREAM OF X
   34 CMINDX(IA,IRUN) = CINT(10,NOX)
      TMINDX(IA)      = TLEN(10)
      IF (MXSEG.EQ.10) GO TO 40
      MXSEG = MXSEG +1
      DO 35 I =MXSEG,10
      IF (CINT(I,NOX)-CMINDX(IA,IRUN)) 36,36,35
   36 CMINDX(IA,IRUN) = CINT(I,NOX)
      TMINDX(IA)      = TLEN(I)
   35 CONTINUE
   40 DATA(IA,NZ) = DATA(IA,NZ) / FACT(NUM)**(TEMPR(IA)-20.)
      RETURN
      END
```

SUBROUTINE K2CAL

```
      SUBROUTINE K2CAL
      COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40),                  10770
     * IREAD(20), CONDE(20,2), CONDI(20,18), DATA(40,94), FINIS(40,9),
     * G(40,20,5), HWFLOW(10,12), INIT(10), IORD(20,20), MONTH(12),
     * JUNC(10,3), TITLE(20), QSCAL(5), TEMPR(40), CMAXM(40,5),
     * CMINUX(40,5), TLMAXM(40,5), XL(40), CT(40)
      COMMON EPSI(40), SEPSI(40), XACT(40,5), CMINUM(40,5), TMINUM(40),
     * CMINDM(40,5), NDOPT(40), K2OPT(40), NSOC(20,28), NSTAT(20),
     * XORD(5),YORD(5), QT(40,9), MSK(40,5), NJC(10), ICPY(10),
     * FIRST(40), STATE(40), NDAYS(40), STATF1(40), FIRST1(40)
      COMMON KONTS(40,2), NTOTS(40,2), NDAYS1(40), KOUNT(40,2), PREV(40)
     * , NTOT(40,2), PREV1(40), Q(31,20), TS(40,2), TSS(40,2), TUP(40),
     * TDOWN(40), DELTA(40), HTH(40), CMINDX(40,5), TMINUX(40),
     * TMINDX(40),TMINDM(40),X1(40,5,2),Y1(40,5),DEFC(40),TCOMP(40,2)
      COMMON CINT(10,4), TLEN(10), NSEG(20), MNPLCY(40),TL(40)
      COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JQ, JU, JX, JY,
     * JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSFAS, TA,AACUP,BBCUP,
     *CCUP1,CCUP2,CCUP3,CCUP4,CCUP5,CCUP6,CCUP7, CCRON, A3, DRENTH,
     * ELEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NI, NINIT, NOX, MZ,
     * MY, MZY, NJUNC, NTRIB, NREA, NACC, DENOM, ESYS, TOTCST, CHECK
C
C           A VALUE OF DEPTH IS OBTAINED FROM ONE OF TWO OPTIONS
C           NDPT = 1, SIGNIFIES OPTION 1 - A VALUE FOR DEPTH IS READ IN
C           NDPT = 2, SIGNIFIES OPTION 2 - DEPTH IS COMPUTED BY A
C           -         REGRESSION EQUATION
      NDPT = NDOPT(IA)
      IF (NDPT.EQ.2) GO TO  5
      DEPTH = DATA (IA,14)
      GO TO 70
    5 DEPTH = DATA (IA,15) * (FINIS(IA,4) ** DATA(IA,16))
   70 CONTINUE
C
C           A VALUE FOR REAERATION RATE IS OBTAINED FROM ONE OF THREE OPTIONS 10870
C           IOPT = 1, SIGNIFIES OPTION 1 - A VALUE IS READ IN
C           IOPT = 2, SIGNIFIES OPTION 2 - K17   IS A FUNCTION OF VELOCITY
C           -         AND DEPTH
C           IOPT = 3, SIGNIFIES OPTION 3 - K17   IS A FUNCTION OF FLOW
C
      IOPT=K2OPT(IA)
      GO TO (1,2,3),   IOPT
    1 DATA (IA,94) = DATA(IA,8)
      GO TO 100
    2 DATA (IA,94) =  DATA(IA,9)* (FINIS(IA,7)**DATA(IA,10)) /(DEPTH**     10980
     *DATA(IA,11)) * 2.31
      GO TO 100
    3 DATA (IA,94) =  DATA(IA,12)* (FINIS(IA,4) ** DATA(IA,13)) *2.31       11020
  100 CONTINUE
C                                                                           11050
C          COMPUTE  K17   WITH TEMPERATURE DEPENDENCE
C
      DATA (IA,94) = DATA(IA,94) * 1.0159** (TEMPR(IA)-20.)
C
C          IF SENSITIVITY ANALYSIS FOR REACTION RATES, MULTIPLY REAERATION
C          RATE BY ITS SCALING FACTOR
      FINIS(IA,8) = DEPTH
C
      RETURN                                                                11060
      END                                                                   11100
                                                                            11110
```

SUBROUTINE DECAY

```
       SUBROUTINE DECAY
       COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40),
      * IREAD(20), CONDE(20,2), CONDI(20,18), DATA(40,94), FINIS(40,9),
      * G(40,20,5), HWFLOW(10,12), INIT(10), IORD(20,20), MONTH(12),
      * JUNC(10,3), TITLE(20), QSCAL(5), TEMPR(40), CMAXM(40,5),
      * CMINUX(40,5), TLMAXM(40,5), XL(40), CT(40)
       COMMON EPSI(40), SEPSI(40), XACT(40,5), CMINUM(40,5), TMINUM(40),
      * CMINDM(40,5), NDOPT(40), K20PT(40), NSOC(20,28), NSTAT(20),
      * XORD(5),YORD(5), QT(40,9), MSK(40,5), NJC(10), ICPY(10),
      * FIRST(40), STATE(40), NDAYS(40), STATE1(40), FIRST1(40)
       COMMON KONTS(40,2), NTOTS(40,2), NDAYS1(40), KOUNT(40,2), PREV(40)
      * , NTOT(40,2), PREV1(40), Q(31,20), TS(40,2), TSS(40,2), TUP(40),
      * TDOWN(40), DELTA(40), HTH(40), CMINDX(40,5), TMINUX(40),
      * TMINDX(40),TMINDM(40),X1(40,5,2),Y1(40,5),DEFC(40),TCOMP(40,2)
       COMMON CINT(10,4), TLEN(10), NSEG(20), MNPLCY(40),TL(40)
       COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JQ, JU, JX, JY,
      * JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSFAS, TA,AACUP,BBCUP,
      *CCUP1,CCUP2,CCUP3,CCUP4,CCUP5,CCUP6,CCUP7, CCRON, A3, DBENTH,
      * ELEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NI, NINIT, NOX, MZ,
      * MY, MZY, NJUNC, NTRIB, NREA, NACC, DENOM, ESYS, TOTCST, CHECK
       LOGICAL CACT
       COMMON/REACT/FACT(20)
       DATA (FACT(I),I=1,20)/0.,0.,0.,0.,0.,0.,0.,1.30,1.20,1.07,1.07,
      *1.047,1.07,1.06,1.08,1.07,1.0159,0.,0.,0./
C
       TA= FINIS(IA,6)
       DATA(IA,NZ) = DATA(IA,NZ) *FACT(NUM) **(TEMPR(IA)-20.)
       DEP=DATA(IA,14)
       IF(NZ.EQ.89.AND.DEP.LT.10.) DATA(IA,NZ)=10.**(-.44*ALOG10(DATA(IA,
      *14))+.04)
C
C            COMPUTES EXPONENTIAL DECAY OF THE CONCENTRATION OF NON-CONSERVATIVE
C            - NON-COUPLED PARAMETERS
C
       B = TA * (-DATA(IA,NZ))
C
       DD = EXP (B)
C
       FINIS(IA,9) = DD * G(IA,NUM,IRUN)
C
       IF (CACT) 39,40
    39 TA = (FINIS(IA,2)-XL(IA)) / (FINIS(IA,7)*16.36)
       B = TA * (-DATA(IA,NZ))
       DD = EXP(B)
       XACT(IA,IRUN) = DD*G(IA,NUM,IRUN)
C            RETURNS TO CALLER TRIBD
    40 DATA(IA,NZ) = DATA(IA,NZ) / FACT(NUM)**(TEMPR(IA)-20.)
       RETURN
       END
```

SUBROUTINE RMATC

```
      SUBROUTINE RMATC
      COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40),
     * IREAD(20), CONDE(20,2), CONDI(20,18), DATA(40,94), FINIS(40,9),
     * G(40,20,5), HWFLOW(10,12), INIT(10), IORD(20,20), MONTH(12),
     * JUNC(10,3), TITLE(20), QSCAL(5), TEMPR(40), CMAXM(40,5),
     * CMINUX(40,5), TLMAXM(40,5), XL(40), CT(40)
      COMMON EPSI(40), SEPSI(40), XACT(40,5), CMINUM(40,5), TMINUM(40),
     * CMINDM(40,5), NDOPT(40), K20PT(40), NSOC(20,28), NSTAT(20),
     * XORD(5),YORD(5), QT(40,9), MSK(40,5), NJC(10), ICPY(10),
     * FIRST(40), STATE(40), NDAYS(40), STATE1(40), FIRST1(40)
      COMMON KONTS(40,2), NTOTS(40,2), NDAYS1(40), KOUNT(40,2), PREV(40)
     * , NTOT(40,2), PREV1(40), Q(31,20), TS(40,2), TSS(40,2), TUP(40),
     * TDOWN(40), DELTA(40), HTH(40), CMINDX(40,5), TMINUX(40),
     * TMINDX(40),TMINDM(40),X1(40,5,2),Y1(40,5),DEFC(40),TCOMP(40,2)
      COMMON CINT(10,4), TLEN(10), NSEG(20), MNPLCY(40),TL(40)
      COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JO, JU, JX, JY,
     * JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSFAS, TA,AACUP,BBCUP,
     *CCUP1,CCUP2,CCUP3,CCUP4,CCUP5,CCUP6,CCUP7, CCRON, A3, DBENTH,
     * ELEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NI, NINIT, NOX, MZ,
     * MY, MZY, NJUNC, NTRIB, NREA, NACC, DENOM, ESYS, TOTCST, CHECK
C
C           DETERMINE WHICH STRETCHES ENTER A JUNCTION
C
      IINIT=NINIT
16    DO 4 I=1,NJUNC
      DO 5 J=1,IINIT
      IF(JUNC(I,1)-INIT(J))5,6,5
5     CONTINUE
      GO TO 4
6     DO 7 J=1,IINIT
      IF(JUNC(I,2)-INIT(J))7,8,7
7     CONTINUE
      GO TO 4
8     II=JUNC(I,1)
      JJ=JUNC(I,2)
C
C
      KK=JUNC(I,3)
      JA=KK
C
C                                          CALL  B L E N D
C
      CALL BLEND
C
C
      FINL = CONDI (JA,NUM)
      QUP    = CONDI(JA,18)
C
C
C                                          CALL  T R I B D
C
      CALL TRIBD
C
C                                          SET FINAL CONDITIONS EQUAL
C                                          TO CALCULATED CONDITIONS
C
      CONDE(JA,1)    = FINL
      CONDE(JA,2)   = QUP
C
C          REPEAT UNTIL ALL JUNCTIONS HAVE BEEN CONSIDERED
C
      IINIT=IINIT+1
      INIT(IINIT) = KK
4     CONTINUE
C
15    RETURN
      END
```

SUBROUTINE BLEND

```
      SUBROUTINE BLEND
      COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40),
     * IREAD(20), CONDE(20,2), CONDI(20,18), DATA(40,94), FINIS(40,9),
     * G(40,20,5), HWFLOW(10,12), INIT(10), IORD(20,20), MONTH(12),
     * JUNC(10,3), TITLE(20), QSCAL(5), TEMPR(40), CMAXM(40,5),
     * CMINUX(40,5), TLMAXM(40,5), XL(40), CT(40)
      COMMON EPSI(40), SEPSI(40), XACT(40,5), CMINUM(40,5), TMINUM(40),
     * CMINDM(40,5), NDOPT(40), K2OPT(40), NSOC(20,28), NSTAT(20),
     * XORD(5),YORD(5), QT(40,9), MSK(40,5), NJC(10), ICPY(10),
     * FIRST(40), STATE(40), NDAYS(40), STATE1(40), FIRST1(40)
      COMMON KONTS(40,2), NTOTS(40,2), NDAYS1(40), KOUNT(40,2), PREV(40)
     * , NTOT(40,2), PREV1(40), Q(31,20), TS(40,2), TSS(40,2), TUP(40),
     * TDOWN(40), DELTA(40), HTH(40), CMINDX(40,5), TMINUX(40),
     * TMINDX(40),TMINDM(40),X1(40,5,2),Y1(40,5),DEFC(40),TCOMP(40,2)
      COMMON CINT(10,4), TLEN(10), NSEG(20), MNPLCY(40),TL(40)
      COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JQ, JU, JX, JY,
     * JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSFAS, TA,AACUP,BBCUP,
     *CCUP1,CCUP2,CCUP3,CCUP4,CCUP5,CCUP6,CCUP7, CCRON, A3, DBENTH,
     * ELEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NI, NINIT, NOX, MZ,
     * MY, MZY, NJUNC, NTRIB, NREA, NACC, DENOM, ESYS, TOTCST, CHECK
C
C            COMPUTES THE DOWNSTREAM FLOW AT A JUNCTION BY ADDING THE
C            TWO UPSTREAM FLOW
C
      CONDI(KK,18) = CONDE(JJ, 2) + CONDE(II, 2)
C
C            COMPUTES DOWNSTREAM CONCENTRATION OF A PARAMETER BY USING
C            - A WEIGHTED MASS BALANCE FORMULA
C
      CONDI(KK,NUM)= ((CONDE(JJ, 2) * CONDE(JJ, 1)) + (CONDE(II, 2)*COND
     *E(II, 1))) / CONDI(KK,18)
C
C            RETURN TO CALLER RMATC
C
      RETURN
      END
```

SUBROUTINE ICSSMU

The listing for Subroutine ICSSMU is not presented in this report to limit distribution of the IMSL proprietary subroutine. An interpreted FORTRAN source deck for ICSSMU is supplied to EPA with the total program source deck.

SUBROUTINE EXPDUR

```
       SUBROUTINE EXPDUR
       COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40),
      * IREAD(20), CONDE(20,2), CONDI(20,18), DATA(40,94), FINIS(40,9),
      * G(40,20,5), HWFLOW(10,12), INIT(10), IORD(20,20), MONTH(12),
      * JUNC(10,3), TITLE(20), QSCAL(5), TEMPR(40), CMAXM(40,5),
      * CMINUX(40,5), TLMAXM(40,5), XL(40), CT(40)
       COMMON EPSI(40), SEPSI(40), XACT(40,5), CMINUM(40,5), TMINUM(40),
      * CMINDM(40,5), NDOPT(40), K20PT(40), NSOC(20,28), NSTAT(20),
      * XORD(5),YORD(5), QT(40,9), MSK(40,5), NJC(10), ICPY(10),
      * FIRST(40), STATE(40), NDAYS(40), STATE1(40), FIRST1(40)
       COMMON KONTS(40,2), NTOTS(40,2), NDAYS1(40), KOUNT(40,2), PREV(40)
      * , NTOT(40,2), PREV1(40), Q(31,20), TS(40,2), TSS(40,2), TUP(40),
      * TDOWN(40), DELTA(40), HTH(40), CMINDX(40,5), TMINUX(40),
      * TMINDX(40),TMINDM(40),X1(40,5,2),Y1(40,5),DEFC(40),TCOMP(40,2)
       COMMON CINT(10,4), TLEN(10), NSEG(20), MNPLCY(40),TL(40)
       COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JQ, JU, JX, JY,
      * JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSFAS, TA,AACUP,BBCUP,
      *CCUP1,CCUP2,CCUP3,CCUP4,CCUP5,CCUP6,CCUP7, CCRON, A3, DBENTH,
      * ELEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NI, NINIT, NOX, MZ,
      * MY, MZY, NJUNC, NTRIB, NREA, NACC, DENOM, ESYS, TOTCST, CHECK
       COMMON/BLK/MASK(40)
       COMMON/BLOCK2/TIME,NMR,DTYPE,POPT
       LOGICAL FIRST,STATE, INOT, PREV, DBLSTR,EOF,IMPL,
      *NCALL, MASK, FIRST1, STATE1, INIT1, PREV1
       LOGICAL MSK,ASTATE,CHEC ,TEST,VUPS,VDNS,ICPY,VXN,VXC,
      * VMAX, VMINUM,VMINDM, VMINUX,VMINDX
       MAX = NREA + 1
       NSTATE = 0
       J = NUM
C  DETERMINE IMPLEMENTATION SCHEME FOR EACH PARAMETER
       DO 1 I = 1,NREA
        NRJ  = 1
        NPATH = 1
        DO 49 MTZ = 1,5
    49 MSK(I,MTZ) = .FALSE.
C  TEST FOR IMPLEMENTED SEGMENTS
         IF (IMPL(I).AND.MASK(J)) 2,1
C  DETERMINE STRETCH OF IMPLEMENTED ELEMENT
     2  DO 3 IX = 1,NTRIB
         DO 3 JP = 1,20
         NSX = IX
         NRX = JP
         IF (I.EQ.IORD(NSX,NRX)) 80,3
     3  CONTINUE
C  DETERMINE IF SEGMENT IS AT THE HEAD OF A STRETCH
    80 NCR = I
    74  IF(NCR.EQ.IORD(NSX,1))    76,75
C  IF NOT AT THE HEAD OF A STRETCH, DETERMINE NEXT UPSTREAM SEGMENT
C  IN CORRESPONDING STRETCH
    75  NRX = NRX - 1
        NCR = IORD (NSX,NRX)
C  SET BITS ON MSK (A WORD INDICATING WHAT SEGMENTS LIE BETWEEN
C  IMPLEMENTED STATIONS K AND K-Y(N)
    78  MSK(I,NPATH)  = MSK(I,NPATH).OR.MASK(NCR)
C  IS UPSTREAM SEGMENT IMPLEMENTED
         IF (IMPL(NCR).AND.MASK(J))  91,74
C  SEGMENT IS AT THE HEAD OF A REACH
C  IS THERE A JUNCTION
    76  DO 77 IX = 1,NJUNC
         NJX = IX
         IF (NSX.EQ.JUNC(NJX,3)) 85,77
    77  CONTINUE
       MSK(I,NPATH)=.FALSE.
       GO TO 20
```

```
C  THERE IS ANOTHER UPSTREAM JUNCTION
C  COPY MASK
   85  ICPY(NRJ) = MSK(I,NPATH)
C  SET SEQUENTIAL JUNCTION LIST
       NJC(NRJ)    = NJX
       NRJ = NRJ + 1
       NSX = JUNC(NJX,1)
       DO 86 JP = 1,20
       IF (IORD(NSX,JP ).EQ.0) GO TO 78
C  FIND NEXT UPSTREAM SEGMENT IN FIRST BRANCH OF JUNCTION
       NRX = JP
       NCR = IORD(NSX,NRX)
   86  CONTINUE
      GO TO 78
C  IF AN IMPLEMENTED STATION IS FOUND BEFORE HEADWATER SEGMENT,
C  INCREMENT NO. OF PATHS
   91  NPATH = NPATH + 1
C  UPSTREAM SEGMENT IS IMPLEMENTED OR A HEADWATER SEGMENT IS REACHED
C  BEFORE AN IMPLEMENTED SEGMENT IS FOUND
C
C  DETERMINE IF THERE ARE ANY PREVIOUS JUNCTIONS
   20 IF  (NRJ.GT.1) 25,1
   25 NRJ = NRJ - 1
      NJX = NJC(NRJ)
C  SEARCH REMAINING BRANCH OF REMAINING JUNCTIONS FOR IMPLEMENTED SEGMENTS
      NSX = JUNC (NJX,2)
C  DETERMINE NEXT UPSTREAM SEGMENT ABOVE THE JUNCTION
      DO 87 JP = 1,20
      IF (IORD(NSX,JP ).EQ.0) GO TO 88
      NRX = JP
      NCR = IORD(NSX,NRX)
   87 CONTINUE
   88 MSK(I,NPATH) = ICPY(NRJ)
      GO TO 78
    1 CONTINUE
C  CHECK IF EACH SEGMENT IS ASSOCIATED WITH A USGS GAUGING STATION
    4 DO 400 I  = 1,NREA
      FIRST(I) =.TRUE.
      PREV(I) = .FALSE.
      STATE(I) = .FALSE.
      NDAYS(I) = 0
      NDAYS1(I) = 0
      FIRST1(I) = .TRUE.
      STATE1(I) = .FALSE.
      PREV1(I) = .FALSE.
      DO 400 KK=1,2
      KONTS(I,KK) = 0
      NTOTS(I,KK) = 0
      KOUNT(I,KK) = 0
      NTOT(I,KK) = 0
  400 CONTINUE
C  READ USGS TAPE FOR ALL MONTHS
C  REPEAT FOR EACH PARAMETER
      NMN = 0
    6 CALL GSTAPE (NMN)
      IF (NMN.EQ.NMR) NSTATE = 1
C  DETERMINE THE NUMBER OF DAYS IN THE CURRENT MONTH
      GO TO (7,9,7,8,7,8,7,7,8,7,8,7),MON
    7 MAXDAY=31
      GO TO 10
    8 MAXDAY=30
      GO TO 10
    9 YEAR=NYEAR
      FRACT=YEAR/4.0
      INTEG=NYEAR/4
      FRACT=FRACT-INTEG
      MAXDAY=29
      IF(FRACT.NE.0.) MAXDAY=28
```

```
C  LOOP FOR DAYS
   10 DO 24 IDAY=1,MAXDAY
C  SET UP WORDS INDICATING WHETHER A VIOLATION OCCURS OR NOT AT EACH
C  SEGMENT FOR THE DAY IN CONCERN
      VUPS = .FALSE.
      VDNS = .FALSE.
      VMAX = .FALSE.
      VMINUM = .FALSE.
      VMINDM = .FALSE.
      VMINUX = .FALSE.
      VMINDX = .FALSE.
      VXC = .FALSE.
      VXN = .FALSE.
      DO 500 I=1,NREA
      DO 66 KX = 1,20
      IF (NSTAT(KX).EQ.0) GO TO 66
      DO 666 IT = 1,28
      IF (NSOC(KX,IT).EQ.I) 667,668
  667 NGS = KX
      GO TO 445
  668 IF (NSOC(KX,IT) .EQ.0) GO TO 66
  666 CONTINUE
   66 CONTINUE
  445 IF (J.GE.14) GO TO 82
      IF (Q(IDAY,NGS).EQ.VALMIS) 671,669
C  IF UPSTREAM END OF SEGMENT IS IN VIOLATION, TURN ON CORRESPOND ING BIT
  669 IF (Q(IDAY,NGS).LE.QT(I,1)) VUPS = VUPS.OR.MASK(I)
C  IF DOWNSTREAM END OF SEGMENT IS IN VIOLATION, TURN ON CORRESPONDING BIT
      IF (Q(IDAY,NGS).LE.QT(I,2))  VDNS=VDNS.OR.MASK(I)
      IF (IMPL(I).AND.MASK(J)) 81,500
   81 IF (Q(IDAY,NGS).LE.QT(I,3))  VXN = VXN.OR.MASK(I)
      GO TO 500
  671 IF (PREV(I).AND.MASK(J)) 672,772
  672 VUPS = VUPS.OR.MASK(I)
      VDNS = VDNS.OR.MASK(I)
  772 IF (IMPL(I).AND.MASK(J)) 773,500
  773 IF (PREV1(I).AND.MASK(J)) VXN = VXN.OR.MASK(J)
      GO TO 500
   82 IF (Q(IDAY,NGS).EQ.VALMIS) 673,674
  674 IF (Q(IDAY,NGS).LE.QT(I,4)) VMAX = VMAX.OR.MASK(I)
      IF (Q(IDAY,NGS).LE.QT(I,5)) VMINUM = VMINUM.OR.MASK(I)
      IF (Q(IDAY,NGS).LE.QT(I,6)) VMINUM = VMINDM.OR.MASK(I)
      IF (IMPL(I).AND.MASK(J)) 83,500
   83 IF (Q(IDAY,NGS).LE.QT(I,7)) VXC = VXC.OR.MASK(I)
      IF (Q(IDAY,NGS).LE.QT(I,8)) VMINUX = VMINUX.OR.MASK(I)
      IF (Q(IDAY,NGS).LE.QT(I,9)) VMINDX = VMINDX.OR.MASK(I)
      GO TO 500
  673 IF (PREV(I).AND.MASK(J)) 675,676
  675 VMAX = VMAX.OR.MASK(I)
      VMINUM = VMINUM.OR.MASK(I)
      VMINDM = VMINDM .OR.MASK(I)
  676 IF (IMPL(I).AND.MASK(J)) 677,500
  677 IF (PREV1(I).AND.MASK(J)) 678,500
  678 VXC = VXC.OR.MASK(J)
      VMINUX = VMINUX.OR.MASK(I)
      VMINDX = VMINDX.OR.MASK(I)
  500 CONTINUE
C  INITIALIZE INDEX FOR SEGMENTS
      I = 1
C  TEST FOR VIOLATION
   46 IF (J.LE.13) CHEC  = VUPS.AND.MASK(I)
      IF (J.GE.14) CHEC  = VMAX.AND.MASK(I)
      IF (CHEC ) 13,14
```

```
    13 STATE(I)=STATE(I).OR.MASK(J)
       GO TO 15
    14 STATE(I)=STATE(I).AND..NOT.MASK(J)
    15 IF (FIRST(I).AND.MASK(J))  GO TO 160
       GO TO 16
   160 FIRST(I)=FIRST(I).AND..NOT.MASK(J)
       PREV(I)=STATE(I)
       GO TO 17
C  IF NOT FIRST DAY,        TEST FOR A CHANGE IN STATE
    16 IF(STATE(I).EQ.PREV(I)) 17,99
    17 NDAYS(I) = NDAYS(I) + 1
       GO TO 220
C  IF CHANGE IN STATE, INCREMENT TOTAL TIME AND NO. OF VIOLATIONS
    99 KK=1
       IF(PREV(I).AND.MASK(J)) KK=2
       KOUNT(I,KK) = KOUNT(I,KK) + 1
       NTOT(I,KK) = NTOT(I,KK) +NDAYS(I)
    21 NDAYS(I) = 1
       PREV(I)=STATE(I)
C  TEST IF ELEMENT IS IMPLEMENTED
   220 IF (IMPL(I).AND.MASK(J)) GO TO 225
   271 I = I + 1
       IF (I.EQ.MAX) GO TO 24
C  FIND IMMEDIATE UPSTREAM SEGMENT OF I
       DO 55 INX = 1,NTRIB
       JNX = INX
       DO 55 JZ = 1,20
       IF (IORD(INX,JZ).EQ.I) GO TO 56
    55 CONTINUE
C  TEST IF SEGMENT IS AT THE HEAD OF STRETCH
    56 IF (I.EQ.IORD(JNX,1)) GO TO 57
       MX = I - 1
       GO TO 58
C  CHECK FOR HEADWATER STRETCH OR UPSTREM JUNCTION
    57 DO 59 IP = 1,NJUNC
       LP = IP
       IF (JNX.EQ.JUNC(IP,3)) GO TO 60
    59 CONTINUE
C  SEGMENT IS AT THE HEAD OF A HEADWATER STRETCH,PROCEED TO NEXT SEGMENT
       GO TO 46
C  THERE IS AN IMMEDIATE UPSTREAM JUNCTION
C  CHECK IF EITHER OF THE UPSTREAM SEGMENTS ARE IN VIOLATION
    60 DO 61 KZ = 1, 2
       IZ = JUNC (LP,KZ)
       DO 62 JP = 1,20
C  C  IDENTIFY THE LAST SEGMENT IN THE UPSTREAM STRETCH
    62 IF (IORD(IZ,JP).GT.0) MX=IORD(IZ,JP)
       IF (J.GE.14) GO TO 100
       CHEC  = VDNS.AND.MASK(MX)
       IF (CHEC ) 14,61
   100 IF (VMINUM.AND.MASK(I)) 101,61
   101 IF (VMINDM.AND.MASK(MX)) 14,61
    61 CONTINUE
       GO TO 46
    58 IF (J.GE.14) 103,102
   102 CHEC  = VDNS.AND.MASK(MX)
       IF (CHEC ) 14,46
   103 IF (VMINUM.AND.MASK(I)) 194,46
   104 IF (VMINDM.AND.MASK(MX)) 14,46
C
C
   225 ASTATE = .TRUE.
C  IF NO VIOLATION AT K, STATE IS TO *
       IF (J.GE.14) GO TO 310
       IF (VXN       .AND.MASK(I)) 3010,3100
   310 IF (VXC       .AND.MASK(I)) 3010,3100
  3010 DO 3020 MTZ= 1,5
       IF (MSK(I,MTZ)) GO TO 3020
       NPATH = MTZ - 1
       IF (NPATH.EQ.0) GO TO 316
       GO TO 3050
  3020 CONTINUE
       NPATH = 5
  3050 DO 3000 NP = 1, NPATH
       NPP = NP
```

```
      DO 501 IR=1,NREA
      TEST = MSK(I,NP).AND.MASK(IR)
      IF (TEST) 502,501
  502 IF (J.GE.14) GO TO 311
      IF (TEST.AND.VUPS.AND.VDNS) 501,3000
  311 IF (TEST.AND.VMINUM.AND.VMINDM) 501,3000
  501 CONTINUE
C  IF VIOLATION IS CONTINUOUS ALONG ANY PATH, STATE IS TO *
      IF (J.LE.14) GO TO 3100
      DO 312 IRN= 1,NREA
      NRN = IRN
      IF (MSK(I,NPP).AND.MASK(IRN)) 313,312
  312 CONTINUE
  313 IF (VMINDX.AND.MASK(NRN)) 314,316
  314 IF (VMINUX.AND.MASK(I))  3100,316
 3000 CONTINUE
C  IF VIOLATIONS ARE UNIQUE BETWEEN K AND K-1   ON ALL PATHS , STATE IS T1 *
  316 ASTATE = .FALSE.
C  STATE IS TO *
 3100 IF (ASTATE) STATE1(I)      = STATE1(I)      .AND..NOT.MASK(J)
C  STATE IS T1 *
      IF(.NOT.ASTATE) STATE1(I)      = STATE1(I)      .OR.MASK(J)
  243 IF (FIRST1(I)      .AND.MASK(J)) GO TO 260
      GO TO 246
  260 FIRST1(I)      = FIRST1(I)      .AND..NOT.MASK(J)
      PREV1(I)      = STATE1(I)
      GO TO 247
  246 IF (STATE1(I).EQ.PREV1(I)) 247,250
  247 NDAYS1(I)      = NDAYS1(I)      + 1
      GO TO 271
  250 KK = 1
      IF (PREV1(I)      .AND.MASK(J)) KK=2
      KONTS (I,      KK) = KONTS(I,      KK) + 1
      NTOTS(I,      KK) = NTOTS(I,      KK) + NDAYS1(I)
  251 NDAYS1(I)      = 1
      PREV1(I)      = STATE1(I)
      GO TO 271
   24 CONTINUE
C  READ NEXT MONTH OF TAPE
      IF (NSTATE) 6,6,1001
C  DETERMINE HOW LONG EACH REACH WAS IN FINAL STATE
 1001 DO 696 I=1,NREA
      KK= 1
      IF (STATE(I).AND.MASK(J)) KK=2
      KOUNT(I,KK) = KOUNT(I,KK) + 1
      NTOT(I,KK) = NTOT(I,KK) + NDAYS(I)
      IF (IMPL(I).AND.MASK(J)) 665,696
  665 KK=1
      IF (STATE1(I).AND.MASK(J)) KK=2
      KONTS(I,KK) = KONTS(I,KK) + 1
      NTOTS(I,KK) = NTOTS(I,KK) + NDAYS1(I)
  696 CONTINUE
C  COMPUTE AVERAGE DURATION OF BOTH TYPES OF T* AND T**
      DO 27 KK = 1,2
      DO 27 I = 1,NREA
      TSS(I,KK) = 0.
      TOT = NTOT(I,KK)
      VIOL = KOUNT(I,KK)
      TS(I,      KK) = 0.
      VIOL1 = KONTS(I,      KK)
      TOT1 = NTOTS(I,      KK)
      IF (VIOL.EQ.0.) GO TO 32
      TSS(I,KK) = TOT/VIOL
   32 IF (VIOL1.EQ.0.) GO TO 27
      TS(I,      KK) = TOT1/VIOL1
   27 CONTINUE
      RETURN
   29 WRITE(NJ ,201)
  201 FORMAT(1H1,46HERROR IN USGS DATA DECK, EXECUTION TERMINATED.)
      STOP
      END
```

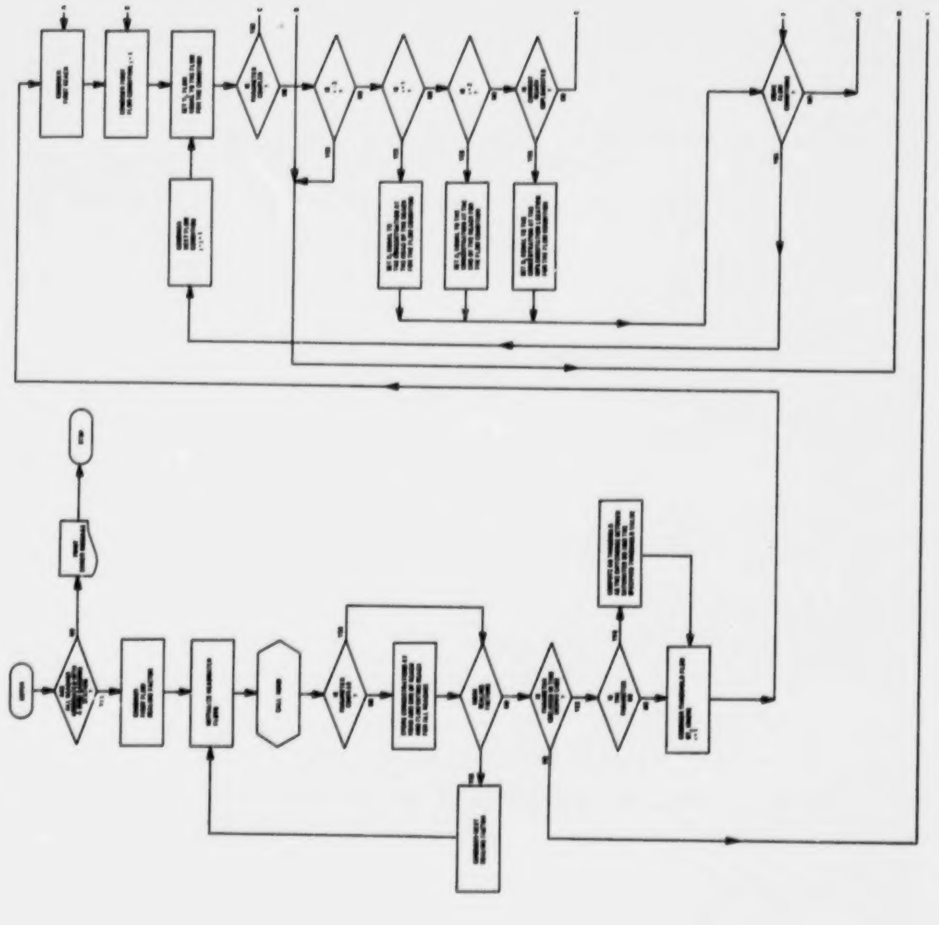


Figure 78. Flowchart for Subroutine QTCAL (Sheet 1 of 2)

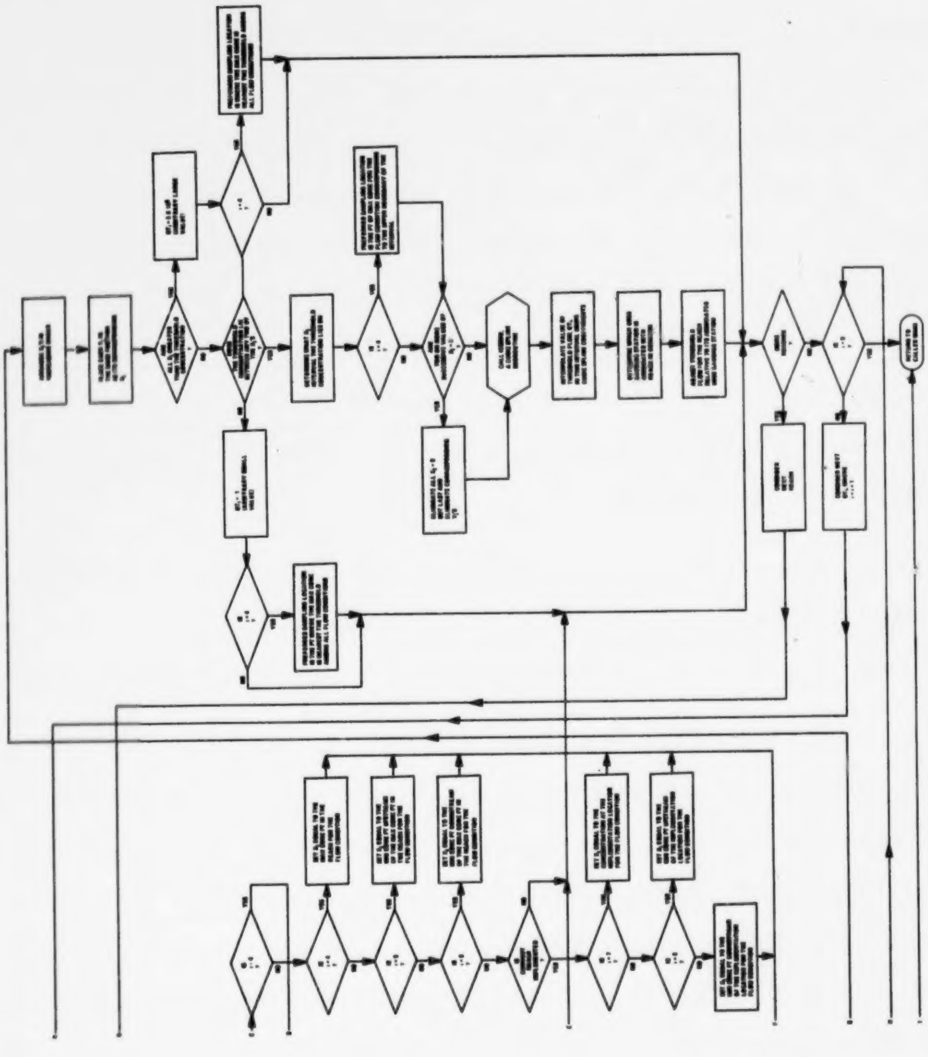


Figure 78. Flowchart for Subroutine QTCAL (Sheet 2 of 2)

SUBROUTINE GSTAPE

As noted in Section VII, Subroutine GSTAPE must be prepared specifically for the computer system being used for design analysis. The objective of GSTAPE is to provide Subroutine EXPDUR with USGS gaging station stream flow data, available to the user from USGS on magnetic tape. GSTAPE is provided with the number of the month required by EXPDUR. GSTAPE must locate and store the flow data from each station required by the design analysis programs for the corresponding month. The necessary stations are those specified in the USGS file of the data deck. The data is stored in the array Q(31, 20) and returned to EXPDUR via COMMON. The first index is the day of the month and the second index corresponds to the USGS station sequence number (not the station ID) specified for each necessary station in the USGS file of the data deck. GSTAPE must also return the month of the year (MON) and the year (NYEAR) to EXPDUR, both via COMMON.

The user should contact the US Geological Survey, Water Resources Division, Automatic Data Section, Washington, D.C. for detailed information on the availability and format of machine processable data for the basin under consideration.

For the Beaver River Basin demonstration case, the data from the 16 gaging stations in the Basin were provided by the USGS on 7-track magnetic tape, prepared on an IBM 360. Data were stored on the tape by station, with all data for each station following in sequence by month. The original tape was processed on Raytheon's UNIVAC 1108 to eliminate extraneous data, reformat to card image, and produce a tape readable by the Raytheon CDC 6700. Using a FORTRAN IV utility program, a limited amount of data was read from the secondary tape and stored on a mass storage medium (disk file) in the sequence necessary for program use: by month, by station. It is the data on mass storage that is accessed by the Subroutine GSTAPE listed below. This listing is provided to guide the user in preparing a subroutine for use on his equipment. It may not be necessary for a specific user to go through all the preparatory steps necessary on the Raytheon facilities.

```
      SUBROUTINE GSTAPE (NMN)
      COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40),
     * IREAD(20), CONDE(20,2), CONDI(20,18), DATA(40,94), FINIS(40,9),
     * G(40,20,5), HWFLOW(10,12), INIT(10), IORD(20,20), MONTH(12),
     * JUNC(10,3), TITLE(20), QSCAL(5), TEMPR(40), CMAXM(40,5),
     * CMINUX(40,5), TLMAXM(40,5), XL(40), CT(40)
      COMMON EPSI(40), SEPSI(40), XACT(40,5), CMINUM(40,5), TMINUM(40),
     * CMINOM(40,5), NDOPT(40), K2OPT(40), NSOC(20,28), NSTAT(20),
     * XORD(5),YORD(5), QT(40,9), MSK(40,5), NJC(10), ICPY(10),
     * FIRST(40), STATE(40), NDAYS(40), STATE1(40), FIRST1(40)
      COMMON KONTS(40,2), NTOTS(40,2), NDAYS1(40), KOUNT(40,2), PREV(40)
     * , NTOT(40,2), PREV1(40), Q(31,20), TS(40,2), TSS(40,2), TUP(40),
     * TDOWN(40), DELTA(40), HTH(40), CMINDX(40,5), TMINUX(40),
     * TMINDX(40),TMINOM(40),X1(40,5,2),Y1(40,5),DEFC(40),TCOMP(40,2)
      COMMON CINT(10,4), TLEN(10), NSEG(20), MNPLCY(40),TL(40)
      COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JQ, JU, JX, JY,
     * JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSEAS, TA,AACUP,BBCUP,
     *CCUP1,CCUP2,CCUP3,CCUP4,CCUP5,CCUP6,CCUP7, CCRON, A3, DBENTH,
     * ELEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NI, NINIT, NOX, MZ,
     * MY, MZY, NJUNC, NTRIB, NREA, NACC, DENOM, ESYS, TOTCST, CHECK
      DIMENSION INDEX(1537),N(52)
      VALMIS=999999.
      NMN = NMN + 1
      IF (NMN.NE.1) GO TO 20
      CALL OPENMS(2,INDEX,1537,0)
   20 DO 4 NSTA=1,16
      IJ = NMN + (NSTA-1) * 96
      CALL READMS(2,N,52,IJ)
      DO 33 K=1,20
      IF (NSTAT(K).EQ.N(2)) 30,33
   30 NGS = K
      NYEAR = N(3)
      MON = N(4)
      DO 34 I = 1,31
      NN = I + 5*(1 +(I-1)/8)
      Q(I,NGS) = N(NN)
   34 CONTINUE
   33 CONTINUE
    4 CONTINUE
      RETURN
      END
```

SUBROUTINE COMPT

```
      SUBROUTINE COMPT
      COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40),
     * IREAD(20), CONDE(20,2), CONDI(20,18), DATA(40,94), FINIS(40,9),
     * G(40,20,5), HWFLOW(10,12), INIT(10), IORD(20,20), MONTH(12),
     * JUNC(10,3), TITLE(20), QSCAL(5), TEMPR(40), CMAXM(40,5),
     * CMINUX(40,5), TLMAXM(40,5), XL(40), CT(40)
      COMMON EPSI(40), SEPSI(40), XACT(40,5), CMINUM(40,5), TMINUM(40),
     * CMINDM(40,5), NDOPT(40), K2OPT(40), NSOC(20,28), NSTAT(20),
     * XORD(5),YORD(5), QT(40,9), MSK(40,5), NJC(10), ICPY(10),
     * FIRST(40), STATE(40), NDAYS(40), STATE1(40), FIRST1(40)
      COMMON KONTS(40,2), NTOTS(40,2), NDAYS1(40), KOUNT(40,2), PREV(40)
     * , NTOT(40,2), PREV1(40), Q(31,20), TS(40,2), TSS(40,2), TUP(40),
     * TDOWN(40), DELTA(40), HTH(40), CMINDX(40,5), TMINUX(40),
     * TMINDX(40),TMINDM(40),X1(40,5,2),Y1(40,5),DEFC(40),TCOMP(40,2)
      COMMON CINT(10,4), TLEN(10), NSEG(20), MNPLCY(40),TL(40)
      COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JQ, JU, JX, JY,
     * JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSEAS, TA,AACUP,BBCUP,
     *CCUP1,CCUP2,CCUP3,CCUP4,CCUP5,CCUP6,CCUP7, CCRON, A3, DBENTH,
     * ELEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NI, NINIT, NOX, MZ,
     * MY, MZY, NJUNC, NTRIB, NREA, NACC, DENOM, ESYS, TOTCST, CHECK
      COMMON/BLK/MASK(40)
      LOGICAL IMPL,MASK,TCOMP
      DO 3 IR =1,NREA
      IF (TSS(IR,2).EQ.0..AND.TSS(IR,1).EQ.0.) GO TO 5
      VIOLSS(IR,NUM) = 1./ (TSS(IR,2) + TSS(IR,1))
      DENOM = DENOM + VIOLSS(IR,NUM)
      GO TO 7
    5 VIOLSS(IR,NUM) = 0.
    7 DO 3 KK=1,2
      TCOMP(IR,KK) = .FALSE.
      IF (IMPL(IR).AND.MASK(NUM)) 2,3
    2 IF (TS(IR,KK).EQ.0.) GO TO 3
      TCOMP(IR,KK) = .TRUE.
    3 CONTINUE
      RETURN
      END
```

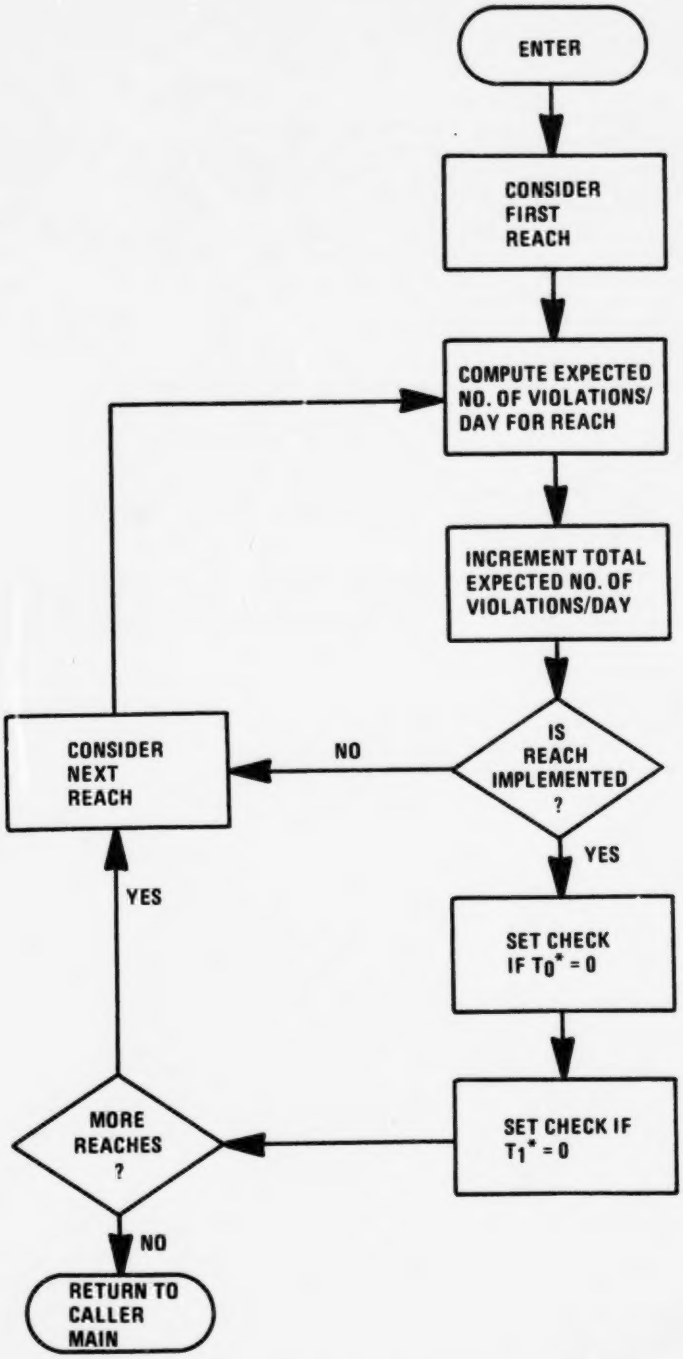

ENTER
CONSIDER FIRST REACH
COMPUTE EXPECTED NO. OF VIOLATIONS/ DAY FOR REACH
INCREMENT TOTAL EXPECTED NO. OF VIOLATIONS/DAY
IS REACH IMPLEMENTED ?
NO
YES
CONSIDER NEXT REACH
SET CHECK IF T0* = 0
SET CHECK IF T1* = 0
MORE REACHES ?
YES
NO
RETURN TO CALLER MAIN

Figure 80. Flowchart for Subroutine COMPT

SUBROUTINE PPDES

```
      SUBROUTINE PPDES
      COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40),
     * IREAD(20), CONDE(20,2), CONDI(20,18), DATA(40,94), FINIS(40,9),
     * G(40,20,5), HWFLOW(10,12), INIT(10), IORD(20,20), MONTH(12),
     * JUNC(10,3), TITLE(20), QSCAL(5), TEMPR(40), CMAXM(40,5),
     * CMINUX(40,5), TLMAXM(40,5), XL(40), CT(40)
      COMMON EPSI(40), SEPSI(40), XACT(40,5), CMINUM(40,5), TMINUM(40),
     * CMINDM(40,5), NDOPT(40), K2OPT(40), NSOC(20,28), NSTAT(20),
     * XORD(5),YORD(5), QT(40,9), MSK(40,5), NJC(10), ICPY(10),
     * FIRST(40), STATE(40), NDAYS(40), STATE1(40), FIRST1(40)
      COMMON KONTS(40,2), NTOTS(40,2), NDAYS1(40), KOUNT(40,2), PREV(40)
     * , NTOT(40,2), PREV1(40), Q(31,20), TS(40,2), TSS(40,2), TUP(40),
     * TDOWN(40), DELTA(40), HTH(40), CMINDX(40,5), TMINUX(40),
     * TMINDX(40),TMINDM(40),X1(40,5,2),Y1(40,5),DEFC(40),TCOMP(40,2)
      COMMON CINT(10,4), TLEN(10), NSEG(20), MNPLCY(40),TL(40)
      COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JQ, JU, JX, JY,
     * JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSEAS, TA,AACUP,BBCUP,
     *CCUP1,CCUP2,CCUP3,CCUP4,CCUP5,CCUP6,CCUP7, CCRON, A3, DBENTH,
     * ELEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NI, NINIT, NOX, MZ,
     * MY, MZY, NJUNC, NTRIB, NREA, NACC, DENOM, ESYS, TOTCST, CHECK
      COMMON/BLOCK2/TIME,NMR,DTYPE,POPT
      PRINT 10,NUM
   10 FORMAT (1H1,//10X,*PARAMETER =*,I3,//,10X,*REACH NO.    EXP. NO. O
     *F    EXP. DURATION OF    EXP. DURATION OF    PREF. SAMPLING*,/,23X
     *,*VIOLATIONS     A VIOLATION          A NON-VIOLATION     LOCATION,
     *R.M.*,//)
      DO 20 I=1,NREA
      IF (NUM.LE.13) PSL=DATA(I,2)
      IF(NUM.GE.14) PSL=TL(I)
      ENV = 365.*TIME*VIOLSS(I,NUM)
      PRINT 30,I,ENV            ,TSS(I,2),TSS(I,1),PSL
   30 FORMAT  (10X,I7,6X,E13.5,5X,E13.5,7X,E13.5,4X,F8.1)
   20 CONTINUE
      RETURN
      END
```

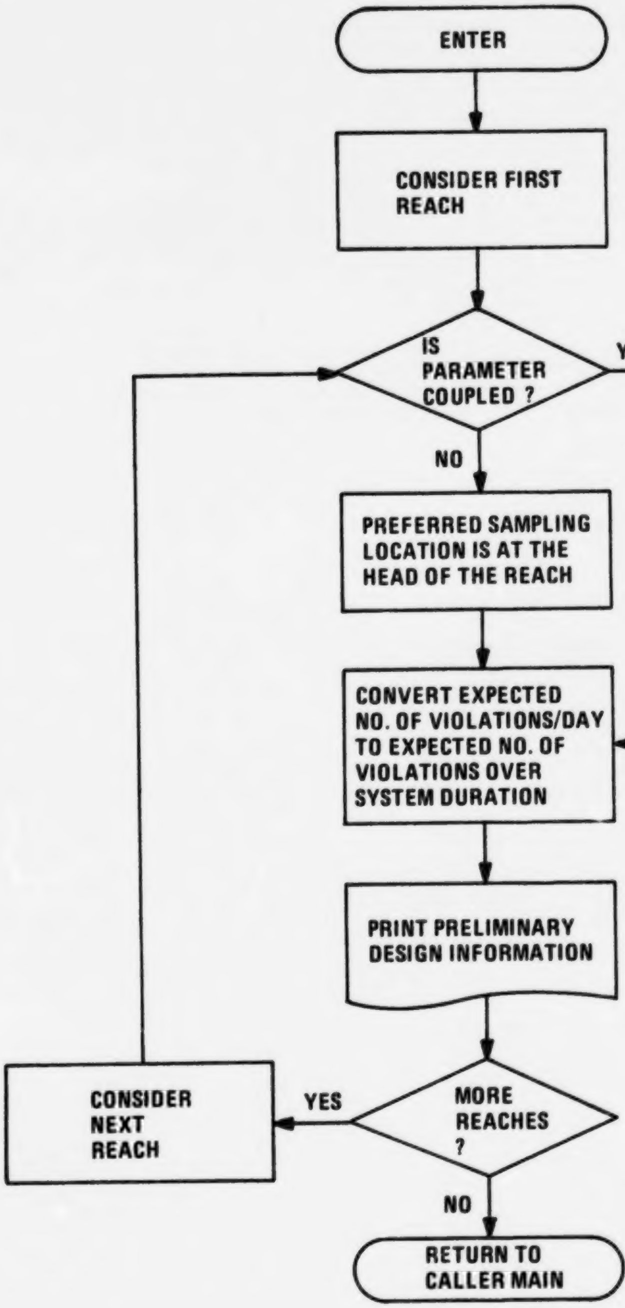

ENTER
CONSIDER FIRST REACH
IS PARAMETER COUPLED ?
YES
PREFERRED SAMPLING LOCATION IS AS DEFINED IN QTCAL
NO
PREFERRED SAMPLING LOCATION IS AT THE HEAD OF THE REACH
CONVERT EXPECTED NO. OF VIOLATIONS/DAY TO EXPECTED NO. OF VIOLATIONS OVER SYSTEM DURATION
PRINT PRELIMINARY DESIGN INFORMATION
MORE REACHES ?
YES
CONSIDER NEXT REACH
NO
RETURN TO CALLER MAIN

Figure 81. Flowchart for Subroutine PPDES

SUBROUTINE CAPBLE

```
      SUBROUTINE CAPBLE
      COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40),
     * IREAD(20), CONDE(20,2), CONDI(20,18), DATA(40,94), FINIS(40,9),
     * G(40,20,5), HWFLOW(10,12), INIT(10), IORD(20,20), MONTH(12),
     * JUNC(10,3), TITLE(20), QSCAL(5), TEMPR(40), CMAXM(40,5),
     * CMINUX(40,5), TLMAXM(40,5), XL(40), CT(40)
      COMMON EPSI(40), SEPSI(40), XACT(40,5), CMINUM(40,5), TMINUM(40),
     * CMINDM(40,5), NDOPT(40), K2OPT(40), NSOC(20,28), NSTAT(20),
     * XORD(5),YORD(5), QT(40,9), MSK(40,5), NJC(10), ICPY(10),
     * FIRST(40), STATE(40), NDAYS(40), STATE1(40), FIRST1(40)
      COMMON KONTS(40,2), NTOTS(40,2), NDAYS1(40), KOUNT(40,2), PREV(40)
     * , NTOT(40,2), PREV1(40), Q(31,20), TS(40,2), TSS(40,2), TUP(40),
     * TDOWN(40), DELTA(40), HTH(40), CMINDX(40,5), TMINUX(40),
     * TMINDX(40),TMINDM(40),X1(40,5,2),Y1(40,5),DEFC(40),TCOMP(40,2)
      COMMON CINT(10,4), TLEN(10), NSEG(20), MNPLCY(40),TL(40)
      COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JQ, JU, JX, JY,
     * JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSEAS, TA,AACUP,BBCUP,
     *CCUP1,CCUP2,CCUP3,CCUP4,CCUP5,CCUP6,CCUP7, CCRON, A3, DBENTH,
     * ELEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NI, NINIT, NOX, MZ,
     * MY, MZY, NJUNC, NTRIB, NREA, NACC, DENOM, ESYS, TOTCST, CHECK
      COMMON/BLK/ MASK(40)
      COMMON/BLOCK2/TIME,NMR,DTYPE,POPT
      LOGICAL IMPL, MASK, MNPLCY,TCOMP
      DO  4 I=1,40
      IF (IMPL(I).AND.MASK(NUM))  6,4
    6 NDOWN=TDOWN(I)  /DELTA(I)
      NUP=TUP(I)  /DELTA(I)
      IF (MNPLCY(I)) GO TO 1
      DELSTR=(NDOWN*DELTA(I)  +TUP(I))  /(NUP+1)
      GO TO 2
    1 DELSTR=(NDOWN+NUP+1)*DELTA(I)  /(NUP+1)
    2 IF (TCOMP(I,1)) 11,12
   11 IF (TCOMP(I,2)) 5,13
    5 E0 = 1.0/EXP(DELSTR/TS(I,1))
      E1 = 1.0/ EXP(DELSTR/TS(I,2))
      DENM  = DELSTR * (TS(I,1)**2 - TS(I,2)**2)
      IF (DENM .EQ.0.)  DENM = 1.
      CAP(I,NUM) =  TS(I,1) * TS(I,2) * (E0-E1)/DENM
      GO TO 7
   12 CAP(I,NUM) = 1.
      GO TO 7
   13 CAP(I,NUM) = 0.
    7 R=TS(I,2)
      DTIM= 365.*TIME
      IF (R.GT.DTIM) R=DTIM
      OBSN = R / DELSTR
      ARG = -EPSI(I) /SEPSI(I)
      PMISS = ANORM(ARG)
      IF (PMISS.EQ.0..AND.OBSN.LE.0.) GO TO 14
      IF (PMISS.EQ.0.) GO TO 4
      R = OBSN * ALOG10(PMISS)
      Z = -5.
      IF (R.LT.Z) GO TO 4
      PMISS = PMISS ** OBSN
      CAP(I,NUM) = CAP(I,NUM)* (1.-PMISS)
      GO TO 4
   14 CAP(I,NUM) = 0.
    4 CONTINUE
      RETURN
      END
```

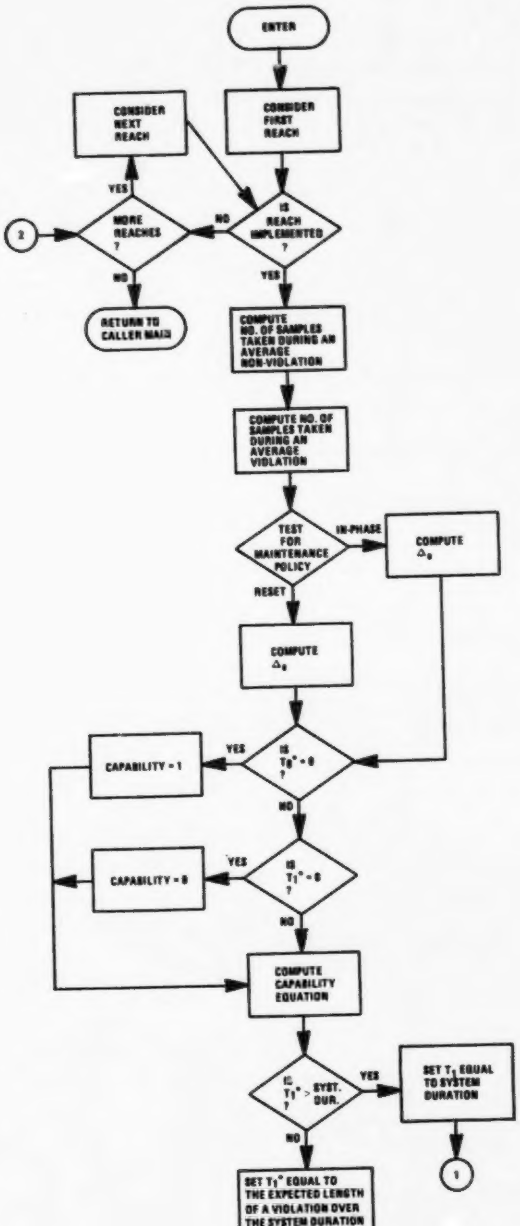

ENTER
CONSIDER FIRST REACH
CONSIDER NEXT REACH
YES
IS REACH IMPLEMENTED ?
NO
2
MORE REACHES ?
NO
RETURN TO CALLER MAIN
YES
COMPUTE NO. OF SAMPLES TAKEN DURING AN AVERAGE NON-VIOLATION
COMPUTE NO. OF SAMPLES TAKEN DURING AN AVERAGE VIOLATION
TEST FOR MAINTENANCE POLICY
IN-PHASE
COMPUTE Δ_e
RESET
COMPUTE Δ_e
YES
IS $T_0^* = 0$?
CAPABILITY = 1
NO
YES
IS $T_1^* = 0$?
CAPABILITY = 0
NO
COMPUTE CAPABILITY EQUATION
IS $T_1^* >$ SYST. DUR. ?
YES
SET T_1 EQUAL TO SYSTEM DURATION
1
NO
SET T_1^* EQUAL TO THE EXPECTED LENGTH OF A VIOLATION OVER THE SYSTEM DURATION
1

Figure 82. Flowchart for Subroutine CAPBLE (Sheet 1 of 2)

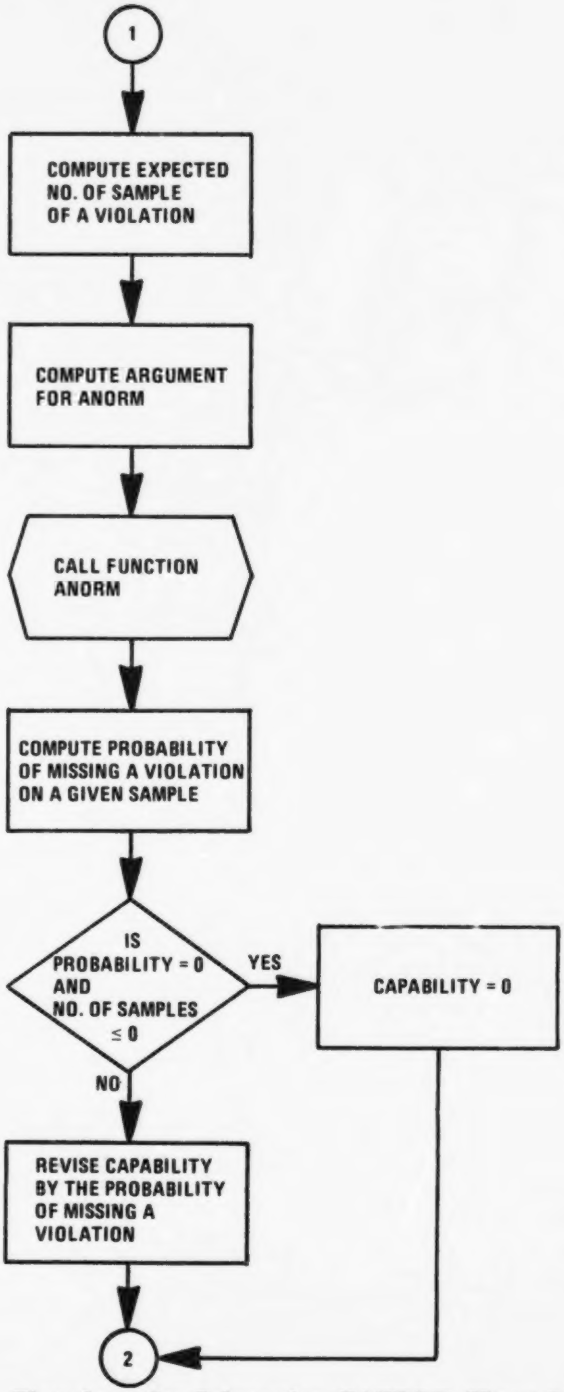

1
COMPUTE EXPECTED NO. OF SAMPLE OF A VIOLATION
COMPUTE ARGUMENT FOR ANORM
CALL FUNCTION ANORM
COMPUTE PROBABILITY OF MISSING A VIOLATION ON A GIVEN SAMPLE
IS PROBABILITY = 0 AND NO. OF SAMPLES ≤ 0
YES
CAPABILITY = 0
NO
REVISE CAPABILITY BY THE PROBABILITY OF MISSING A VIOLATION
2

Figure 82. Flowchart for Subroutine CAPBLE (Sheet 2 of 2)

FUNCTION ANORM

```
      FUNCTION ANORM(ARG)
      DIMENSION BNORM( 66)
      DATA (BNORM(I),I=1,46 )/  .5000,.5199,.5398,.5596,.5793,.5987,
     * .6179,.6368,.6554,.6736,.6915,.7088,.7257,.7422,.7580,.7734,
     * .7881, .8023,.8159,.8289,.8413,.8531,.8643,.8749,.8849,.8944,
     * .9032, .9115,.9192,.9265,.9332,.9394,.9452,.9505,.9554,.9599,
     * .9641, .9678,.9713,.9744,.9772,.9798,.9821,.9842,.9861,.9878/
      DATA (BNORM(I),I=47,66 )/ .9893,.9906,.9918,.9929,.9938,.9946,
     * .9953,.9960,.9965,.9970,.9974,.9978,.9981,.9984,.9987,.9989,
     * .9990,.9992,.9993,.9994 /
C  FIND CUMULATIVE NORMAL DISTRIBUTION OF ARGUMENT
      IF (ARG)  1,2,2
    2 I    =ARG/.05+1
      IF (I.GE.66) GO TO 3
      Z = I-1
      ANORM = BNORM(I) +(ARG - Z *.05)/.05 * (BNORM(I+1)- BNORM(I))
      GO TO 10
    3 ANORM = 1.0
      GO TO 10
    1 I = -ARG/.05+1
      IF (I.GE.66) GO TO 4
      Z = I-1
      ANORM =  .5000 -(BNORM(I)-.5000) +(-ARG-Z*.05)/.05*(BNORM(I+1)-
     *BNORM(I))
      GO TO 10
    4 ANORM =  0.0
   10 RETURN
      END
```

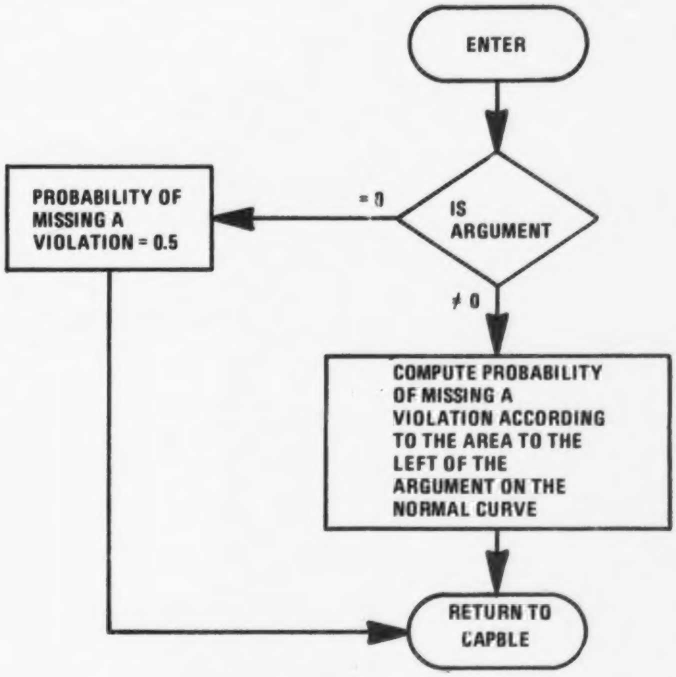

ENTER
IS ARGUMENT
= 0
≠ 0
PROBABILITY OF MISSING A VIOLATION = 0.5
COMPUTE PROBABILITY OF MISSING A VIOLATION ACCORDING TO THE AREA TO THE LEFT OF THE ARGUMENT ON THE NORMAL CURVE
RETURN TO CAPBLE

Figure 83. Flowchart of Function ANORM

SUBROUTINE RMTTF

```
      SUBROUTINE RMTTF
      COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40), IREAD(20),
     * MTTFA(300,2), MTTFS(300,2), MTTRA(300,2), LIST(4), COST(4),
     * MEMBER(100,2), CSTINC(100,2), SDATA(10), NDATA(10), MSYS(10,23),
     * NSAC(64), MINC(5), MPATH(5), MEMB(10), NSTATE(5), PFAIL(10),
     * PCHK(10), NTRANS(5), LEVEL(10), TRANS(64,64), AVAIL(40)
      COMMON COEF(64,64), SRV(40), PROD(65), PROB(65), NST(64),
     * NSFR(64), EFF(40)
      COMMON/BLK/MASK(40)
      COMMON/BLOCK2/TIME,NMR,DTYPE,POPT
      LOGICAL LIST,MASK,POPT
      REAL MTTFA,MTTRA,MTTFS
      DATA END/5HEND  /
      DO 30 K=1,10
      DO 30 L=1,23
   30 MSYS(K,L) =0
      DO 44 I = 1,4
   44 LIST(I) = .FALSE.
      IF (POPT) WRITE (6 ,200)
  200 FORMAT (1H1///,30X,* STATE 1 = OPERATING, STATE 2 = STAND-BY*,//,
     *10X,*MEANS NO..     MTTFS-1      MTTFS-2      MTTFA-1      MTTFA-2
     *MTTRA-1      MTTRA-2*,//)
C  READ MEAN TIME CARDS FOR ALL MEANS
    1 READ (5,100) DUM1,M,MTTFS(M,1),MTTFS(M,2),MTTFA(M,1),MTTFA(M,2),
     * MTTRA(M,1),MTTRA(M,2)
  100 FORMAT (A5,3X,I2,6F10.3)
      IF (DUM1.EQ.END) 3,2
    2 INTEG = 1 + (M-1) /32
      IBIT = M - (INTEG-1)*32
      LIST(INTEG) = LIST(INTEG).OR.MASK(IBIT)
      IF (POPT) WRITE (6 ,300) M,MTTFS(M,1),MTTFS(M,2),MTTFA(M,1),MTTFA(
     *M,2), MTTRA(M,1), MTTRA(M,2)
  300 FORMAT (13X,I3,5X,6(F8.2,4X))
      GO TO 1
    3 RETURN
      END
```

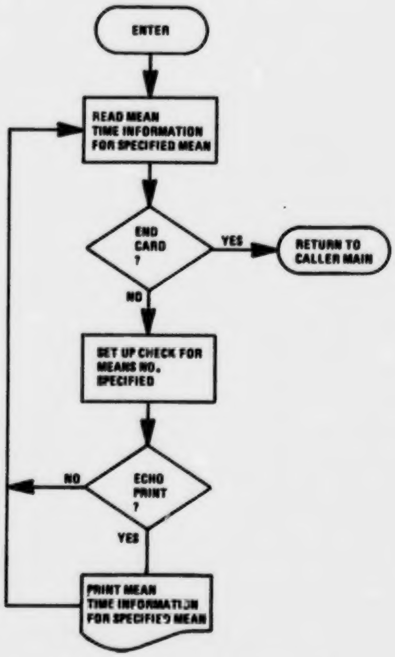

ENTER
READ MEAN TIME INFORMATION FOR SPECIFIED MEAN
END CARD ?
YES
RETURN TO CALLER MAIN
NO
SET UP CHECK FOR MEANS NO. SPECIFIED
ECHO PRINT ?
NO
YES
PRINT MEAN TIME INFORMATION FOR SPECIFIED MEAN

Figure 84. Flowchart of Subroutine RMTTF

SUBROUTINE LMNTEFF

```
      SUBROUTINE LMNTEFF
      COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40), IREAD(20),
     * MTTFA(300,2), MTTFS(300,2), MTTRA(300,2), LIST(4), COST(4),
     * MEMBER(100,2), CSTINC(100,2), SDATA(10), NDATA(10), MSYS(10,23),
     * NSAC(64), MINC(5), MPATH(5), MEMB(10), NSTATE(5), PFAIL(10),
     * PCHK(10), NTRANS(5), LEVEL(10), TRANS(64,64), AVAIL(40)
      COMMON COEF(64,64), SRV(40), PROD(65), PROB(65), NST(64),
     * NSFR(64), EFF(40)
      COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JQ, JU, JX, JY,
     * JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSEAS, TA,AACUP,BBCUP,
     *CCUP1,CCUP2,CCUP3,CCUP4,CCUP5,CCUP6,CCUP7, CCRON, A3, DBENTH,
     * ELEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NI, NINIT, NOX, MZ,
     * MY, MZY, NJUNC, NTRIB, NREA, NACC, DENOM, ESYS, TOTCST, CHECK
      COMMON/BLK/ MASK(40)
      LOGICAL MNPLCY, MASK, IMPL
      DO 40 ITYPE = 1,2
      CALL LDEFF       (ITYPE)
   40 CONTINUE
      WRITE (NJ,60) NUM
   60 FORMAT (1H1,///10X,*PARAMETER NUMBER = *,I3,///)
      DO 50 I = 1,NREA
      IF (IMPL(I).AND.MASK(NUM)) 45,50
   45 TEMP = CAP(I,NUM) * SRV(I) * AVAIL(I)
      WRITE (NJ,70) I,CAP(I,NUM),SRV(I),AVAIL(I),TEMP
   70 FORMAT(/10X,*REACH NO. = *,I3,* CAP = *,E13.5,* SURV = *,E13.5,* A
     *VAIL = *,E13.5,* ELEMENT EFF. = *,E13.5)
      EFF(I) = EFF(I) +TEMP
   50 CONTINUE
      RETURN
      END
```

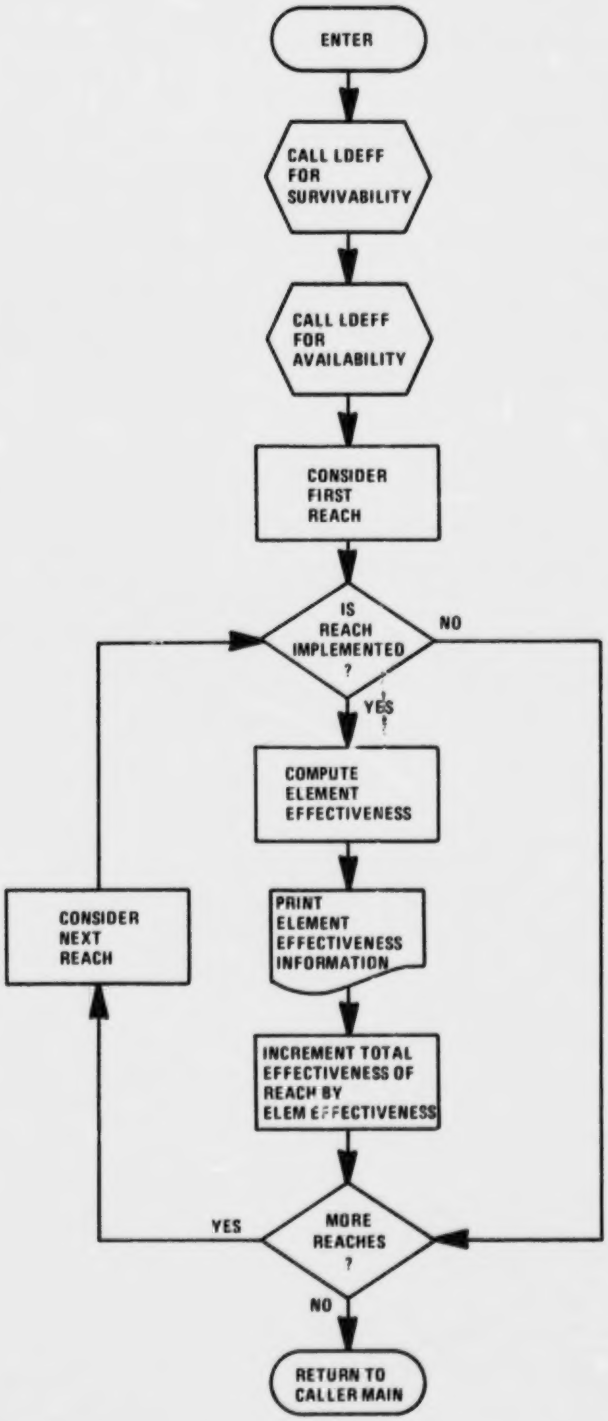

ENTER
CALL LDEFF FOR SURVIVABILITY
CALL LDEFF FOR AVAILABILITY
CONSIDER FIRST REACH
IS REACH IMPLEMENTED ?
NO
YES
COMPUTE ELEMENT EFFECTIVENESS
PRINT ELEMENT EFFECTIVENESS INFORMATION
INCREMENT TOTAL EFFECTIVENESS OF REACH BY ELEM EFFECTIVENESS
CONSIDER NEXT REACH
YES
MORE REACHES ?
NO
RETURN TO CALLER MAIN

Figure 85. Flowchart of Subroutine LMNTFF

SUBROUTINE LDEFF

```
      SUBROUTINE LDEFF      (ITYPE)
      COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40), IREAD(20),
     * MTTFA(300,2), MTTFS(300,2), MTTRA(300,2), LIST(4), COST(4),
     * MEMBER(100,2), CSTINC(100,2), SDATA(10), NDATA(10), MSYS(10,23),
     * NSAC(64), MINC(5), MPATH(5), MEMB(10), NSTATE(5), PFAIL(10),
     * PCHK(10), NTRANS(5), LEVEL(10), TRANS(64,64), AVAIL(40)
      COMMON COEF(64,64), SRV(40), PROD(65), PROB(65), NST(64),
     * NSFR(64), EFF(40)
      COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JQ, JU, JX, JY,
     * JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSFAS, TA, ACUP, BCUP,
     * CUP1, CUP2, CUP3, CUP4, CUP5, CUP6, CUP7, CIRON, A3, DBENTH,
     * ELEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NI, NINIT, NOX, MZ,
     * MY, MZY, NJUNC, NTRIB, NREA, NACC, DENOM, ESYS, TOTCST, CHECK
      COMMON/BLK/ MASK(40)
      COMMON/BLOCK2/TIME,NMR,DTYPE,POPT
      REAL MTTFA,MTTRA,MTTFS
      LOGICAL  MASK    ,MIMP(40), IMPL,ITP,POPT
      DATA END/5HEND  /,S/1HS/,P/1HP/,DM/1HM/,BLANK/1H /
      IX = 0
      NMAX = 1
      DO 70 J = 1,40
   70 MIMP(J) = .FALSE.
C  ITYPE = 1 IMPLIES SURVIVABILITY
C  ITYPE = 2 IMPLIES AVAILABILITY
C
C  READ ELEMENT DESIGN CARDS
C
      IF (.NOT.POPT) GO TO 3
      IF (ITYPE.EQ.1) WRITE (6 ,400) NUM
      IF (ITYPE.EQ.2) WRITE (6 ,410) NUM
  400 FORMAT (1H1,///10X,*PARAMETER NUMBER =*,I3,* ELEMENT DESIGN FOR SU
     *RVIVABILITY*,/)
  410 FORMAT (1H1,///10X,*PARAMETER NUMBER = *,I3,* ELEMENT DESIGN FOR A
     *VAILABILITY*,/)
      WRITE (6 ,420)
  420 FORMAT (10X,*REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN*,
     *//)
    3 READ (5,101) DUM1,I,J,IJP,NORM,(SDATA(L),NDATA(L),L=1,10)
C  CHECK IDS
      IF (DUM1.EQ.END) GO TO 55
      IF (POPT) WRITE (6 ,430) I,IJP,NORM,(SDATA(L),NDATA(L),L=1,10)
  430 FORMAT (10X,I6,6X,I4,9X,I4,8X,10(A1,I2))
C  SET CURRENT ELEMENT
    4 NCURR = 100*I + J
      IF (IX.EQ.0) GO TO 14
C
C  CHECK FOR OLD OR NEW ELEMENT
      IF (NCURR.NE.NTEST)  GO TO 30
C
C  TEST FOR IMPLEMENTATION
C
  230 IF(IMPL(I).AND. MASK(J)) GO TO 14
      MN = I
      NN = J
      NTEST = NCURR
      GO TO 3
   30 IX = IX + 1
      IF (IMPL(MN).AND.MASK(NN)) GO TO 220
      GO TO 360
   55 IF (IMPL(MN).AND. MASK(NN)) GO TO 220
      GO TO 5
C  CHECK FOR PREVIOUS COMPUTATION
  220 IF(MIMP(MN).AND. MASK(NN)) GO TO 998
```

```
C
C  SET CHECK
      MIMP(MN) = MIMP(MN).OR. MASK(NN)
C  ALL PATHS
      IF (MSYS(NMAX,7).EQ.0) GO TO 997
      IF (ITYPE.EQ.2) GO TO 340
C  *** SETUPS ***
      ITP = .FALSE.
      CALL SETUP (NMAX,NSMAX,ITP)
C  *** LPLACE ***
      CALL LPLACE (NSMAX)
C
C  DETERMINE SURVIVABILITY OF ELEMENT
      SUM = 0.
      DO 300 M=1,NSMAX
  300 IF (NSAC(M).EQ.0) SUM = SUM + PROB(M)
      SRV(MN)     = SUM
      GO TO 360
  340 ITP = .TRUE.
      CALL SETUP (NMAX,NSMAX,ITP)
      CALL SOLVE (NSMAX)
      SUM = 0.
      DO 380 M=1,NSMAX
  380 IF (NSAC(M).EQ.0) SUM = SUM + PROB(M)
      AVAIL(MN)    = SUM
C
C  RESET STORAGE
C
  360 DO 35 L=1,NMAX
      DO 35 N=1,23
   35 MSYS(L,N) = 0
      IF (DUM1.EQ.END) GO TO 5
      NMAX = 1
      GO TO 230
C
C  PROCESS AND STORE
C
C  STORE NORMAL STATUS
   14 MSYS(IJP,1) = NORM
      IX = IX + 1
C  CHECK FOR FIRST PATH
      IF (IJP.EQ.1) MSYS(IJP,23) = 1
      NTEST = NCURR
      MN = I
      NN = J
C  FIRST DATA ELEMENT
      M = 1
C
C  ELEMENT TYPE
      NS = 15
      NP = 2
      NM = 7
   10 IF (SDATA(M)  .EQ.DM) GO TO 6
      IF (SDATA(M)  .EQ.P) GO TO 7
      IF (SDATA(M)  .EQ.S) GO TO 8
      GO TO 999
C  STORE IN 7-14
    6 IF (NM.GE.15) GO TO 996
      MSYS(IJP,NM) = NDATA(M)
      NM = NM + 1
      GO TO 9
    7 IF(NP.GE.7) GO TO 996
      MSYS(IJP,NP) =NDATA(M)
      NP = NP + 1
      NT = NDATA(M)
      IF (NT.GT.NMAX) NMAX = NT
      GO TO 9
    8 IF (NS.GE.23) GO TO 996
      MSYS(IJP,NS) = NDATA(M)
      NS = NS + 1
C  SET LEVEL OF PATH
      NT = NDATA(M)
      MSYS(NT,23) = MSYS(IJP,23) + 1
      IF (NT.GT.NMAX) NMAX = NT
C  LAST DAT A ELEMENT
    9 M = M + 1
      IF (SDATA(M)  .NE.BLANK) GO TO 10
      GO TO 3
C  CHECK IF ALL IMPLEMENTED ELEMENTS HAVE BEEN EVALUATED
    5 DO 60 I=1,NREA
      IF (IMPL(I).AND.MASK(NUM)) GO TO 80
      GO TO 60
   80 IF (MIMP(I).AND.MASK(NUM)) GO TO 60
      GO TO 41
   60 CONTINUE
      GO TO 888
   41 WRITE (6,102)
  102 FORMAT (/10X,75HTHE SURVIVABILITY OF ALL IMPLEMENTED ELEMENTS HAS
     *NOT BEEN COMPUTED                          ,//)
      STOP
  999 PRINT 103
  103 FORMAT (/10X,40HTHER ARE ID ERRORS IN INPUT DATA            ,//)
      STOP
  998 PRINT 104
  104 FORMAT (/10X,45HTHIS ELEMENT HAS BEEN PREVIOUSLY COMPUTED
     */)
      STOP
  101 FORMAT (A5,4(3X,I2),10(A1,I2))
  996 PRINT 130
  130 FORMAT (/10X,55HTOO MANY MEANS,PARALLEL PATHS, OR SUBPATHS HAVE BE
     *EN SPECIFIED        ,/)
  997 PRINT 110
  110 FORMAT (/10X,55HINFORMATION FOR ALL PATHS HAS NOT BEEN PROVIDED
     *                    ,/)
      STOP
  888 RETURN
      END
```

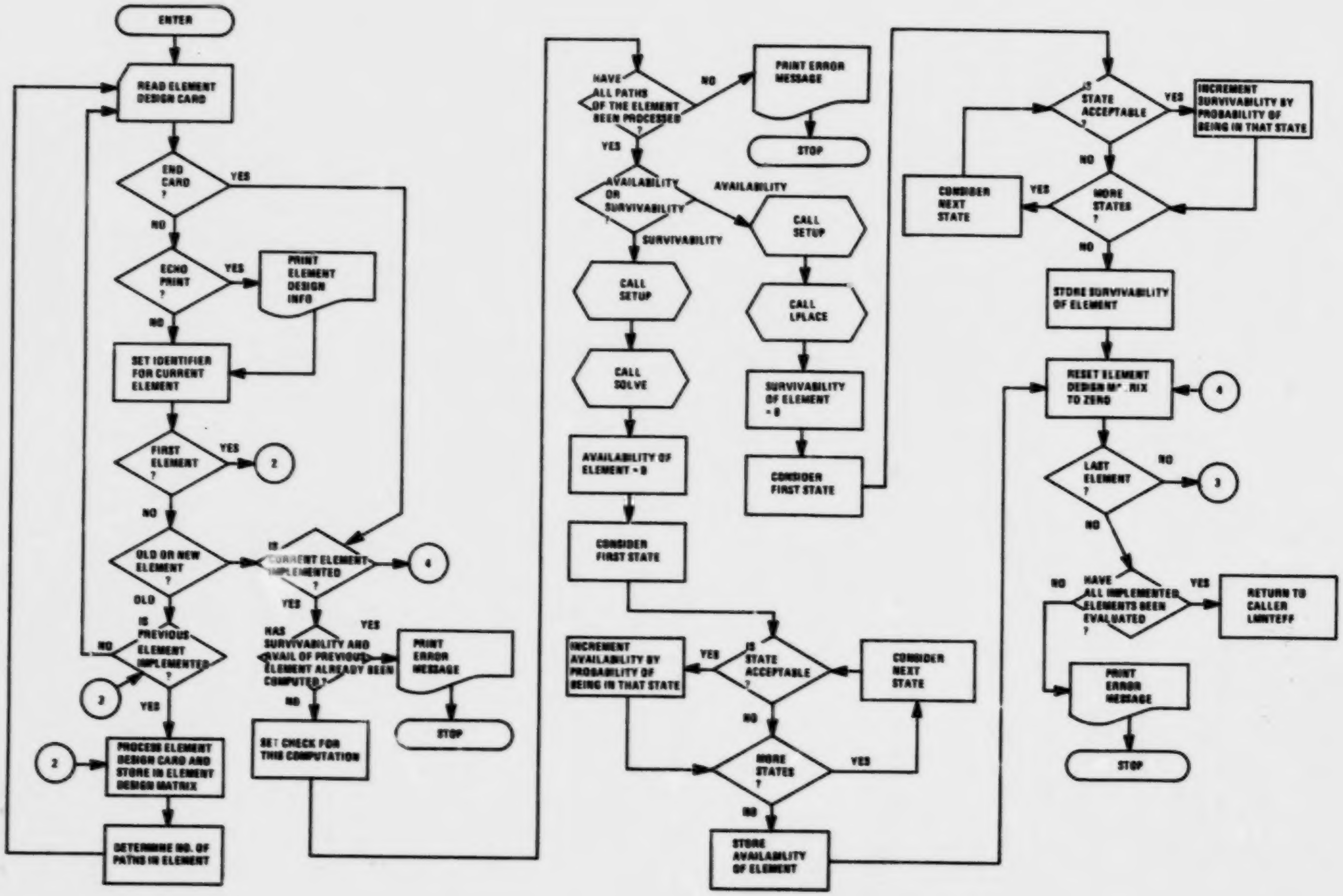

ENTER
READ ELEMENT DESIGN CARD
END CARD ?
YES
NO
ECHO PRINT ?
YES
PRINT ELEMENT DESIGN INFO
NO
SET IDENTIFIER FOR CURRENT ELEMENT
FIRST ELEMENT ?
YES
2
NO
OLD OR NEW ELEMENT ?
OLD
IS PREVIOUS ELEMENT IMPLEMENTED ?
NO
3
YES
2
PROCESS ELEMENT DESIGN CARD AND STORE IN ELEMENT DESIGN MATRIX
DETERMINE NO. OF PATHS IN ELEMENT
IS CURRENT ELEMENT IMPLEMENTED ?
4
YES
HAS SURVIVABILITY AND AVAIL OF PREVIOUS ELEMENT ALREADY BEEN COMPUTED ?
YES
PRINT ERROR MESSAGE
STOP
NO
SET CHECK FOR THIS COMPUTATION
HAVE ALL PATHS OF THE ELEMENT BEEN PROCESSED ?
NO
PRINT ERROR MESSAGE
STOP
YES
AVAILABILITY OR SURVIVABILITY ?
AVAILABILITY
SURVIVABILITY
CALL SETUP
CALL SOLVE
AVAILABILITY OF ELEMENT = 0
CONSIDER FIRST STATE
CALL SETUP
CALL LPLACE
SURVIVABILITY OF ELEMENT = 0
CONSIDER FIRST STATE
INCREMENT AVAILABILITY BY PROBABILITY OF BEING IN THAT STATE
YES
IS STATE ACCEPTABLE ?
CONSIDER NEXT STATE
NO
MORE STATES ?
YES
NO
STORE AVAILABILITY OF ELEMENT
IS STATE ACCEPTABLE ?
YES
INCREMENT SURVIVABILITY BY PROBABILITY OF BEING IN THAT STATE
CONSIDER NEXT STATE
YES
NO
MORE STATES ?
NO
STORE SURVIVABILITY OF ELEMENT
RESET ELEMENT DESIGN MA RIX TO ZERO
4
LAST ELEMENT ?
NO
3
NO
HAVE ALL IMPLEMENTED ELEMENTS BEEN EVALUATED ?
NO
YES
RETURN TO CALLER LMNTEFF
PRINT ERROR MESSAGE
STOP

Figure 86. Flowchart of Subroutine LDEFF

SUBROUTINE SETUP

```
      SUBROUTINE SETUP       (IJPMAX,NSMAX,ITP)
      COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40), IREAD(20),
     * MTTFA(300,2), MTTFS(300,2), MTTRA(300,2), LIST(4), COST(4),
     * MEMBER(100,2), CSTINC(100,2), SDATA(10), NDATA(10), MSYS(10,23),
     * NSAC(64), MINC(5), MPATH(5), MEMB(10), NSTATE(5), PFAIL(10),
     * PCHK(10), NTRANS(5), LEVEL(10), TRANS(64,64), AVAIL(40)
      COMMON COEF(64,64), SRV(40), PROD(65), PROB(65), NST(64),
     * NSFR(64), EFF(40)
      COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JQ, JU, JX, JY,
     * JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSFAS, TA,AACUP,BBCUP,
     *CCUP1,CCUP2,CCUP3,CCUP4,CCUP5,CCUP6,CCUP7, CCRON, A3, DBENTH,
     * ELEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NI, NINIT, NOX, MZ,
     * MY, MZY, NJUNC, NTRIB, NREA, NACC, DENOM, ESYS, TOTCST, CHECK
      REAL MTTFA,MTTRA,MTTFS
      LOGICAL PFAIL    ,PCHK    ,IMPL,ITP
C     THIS SUBROUTINE SETS-UP THE TRANSITION MATRIX FOR A SYSTEM
C     ELEMENT, BASED ON THE MASTER SYSTEM MATRIX AND THE MTTF
C     MATRIX. AS PRESENTLY WRITTEN, IT IS LIMITED TO SIX MEANS
C     PER ELEMENT.
C
C     INITIALIZE ARRAYS
C
      DO 2 NSFROM=1,64
      DO 1 NSTO=1,64
    1 TRANS(NSFROM,NSTO)=0.0
    2 CONTINUE
      DO 3 IJP=1,IJPMAX
    3 MEMB  (IJP)=0
C
C     DETERMINE NO. OF MEANS ASSOCIATED WITH SYSTEM ELEMENT AND
C     ESTABLISH MAPS OF MEANS, PATHS, AND LEVELS
C
      MMAX=0
      DO 6 IJP=1,IJPMAX
      LEVEL(IJP)=MSYS   (IJP,23)
      DO 4 IJPM=7,14
      IF(MSYS   (IJP,IJPM).EQ.0) GO TO 4
      MMAX=MMAX+1
      MINC(MMAX)=MSYS   (IJP,IJPM)
      MPATH(MMAX)=IJP
    4 CONTINUE
      DO 5 IJPS=15,22
      IJP1=MSYS   (IJP,IJPS)
      IF(IJP1.EQ.0) GO TO 5
      MEMB  (IJP1)=IJP
    5 CONTINUE
    6 CONTINUE
C
C     COMPUTE NO. POSSIBLE STATES
C
      NSMAX=2**MMAX
C
C     FOR EACH ROW IN TRANSITION MATRIX, DETERMINE IF FROM-STATE
C     IS ACCEPTABLE, THEN INSERT CORRESPONDING MTTF IN TRANS.
C
      DO 24 NSFROM=1,NSMAX
C
C     CONVERT FROM-STATE TO BINARY
C
      NSFBIN=NSFROM-1
      DO 7 NBIN=1,MMAX
      INVNBN=MMAX-NBIN
      NSTATE(INVNBN+1)=0
      NTEST=NSFBIN-(2**INVNBN)
      IF(NTEST.LT.0) GO TO 7
      NSTATE(INVNBN+1)=1
      NSFBIN=NTEST
    7 CONTINUE
C
C     DETERMINE FAILED PATHS
C
      DO 8 IJP=1,IJPMAX
      PCHK(IJP)=.FALSE.
    8 PFAIL(IJP)=.FALSE.
      MAXLEV=0
      DO 9 NBIN=1,MMAX
      IF(NSTATE(NBIN).EQ.0) GO TO 9
      IJP=MPATH(NBIN)
      PFAIL(IJP)=.TRUE.
      IF(LEVEL(IJP).GT.MAXLEV) MAXLEV=LEVEL(IJP)
    9 CONTINUE
      IF(MAXLEV.EQ.0) GO TO 13
      DO 12 LEV=1,MAXLEV
      INVLEV=MAXLEV-LEV+1
      DO 11 IJP=1,IJPMAX
      IF(.NOT.PFAIL(IJP)) GO TO 11
      IF(LEVEL(IJP).NE.INVLEV) GO TO 11
      IF(PCHK(IJP)) GO TO 11
      PCHK(IJP)=.TRUE.
      NPP=0
      NPPF=0
      DO 10 IJPP=2,6
      IJP1=MSYS    (IJP,IJPP)
      IF(IJP1.EQ.0) GO TO 10
      PCHK(IJP1)=.TRUE.
      NPP=NPP+1
      IF(.NOT.PFAIL(IJP1)) GO TO 10
      NPPF=NPPF+1
   10 CONTINUE
      IF(NPP.EQ.0) GO TO 11
      IF(NPPF.LT.NPP) GO TO 11
      IJP1=MEMB   (IJP)
      PFAIL(IJP1)=.TRUE.
   11 CONTINUE
   12 CONTINUE
C
C     DETERMINE ACCEPTABILITY OF FROM-STATE
C
   13 IF(PFAIL(1)) 14,15
   14 NSAC(NSFROM)=1
      GO TO 16
   15 NSAC(NSFROM)=0
C
C     SET UP ROW IN TRANSITION MATRIX
C
   16 DO 21 NBIN=1,MMAX
      IF (ITP)   GO TO 200
      IF(NSTATE(NBIN).EQ.1) GO TO 21
  200 DO 17 NBINT=1,MMAX
   17 NTRANS(NBINT)=NSTATE(NBINT)
      NTRANS(NBIN) =IABS(NSTATE(NBIN)-1)
C     CONVERT TO-STATE TO DECIMAL
      NSTO=1
      DO 18 NBINT=1,MMAX
   18 NSTO=NSTO+NTRANS(NBINT)*(2**(NBINT-1))
```

```
C     DETERMINE IF MEANS IS STAND-BY OR OPERATING AND INSERT MTTF
      IJP=MPATH(NBIN)
      MFAIL=MINC(NBIN)
      NORM=MSYS    (IJP,1)
      IF (NORM.NE.1) GO TO 230
      IF (ITP) 211,20
  230 NHIP=0
      NHIPF=0
      DO 19 IJPP=2,6
      IJP1=MSYS    (IJP,IJPP)
      IF(IJP1.EQ.0) GO TO 19
      NORPAR=MSYS    (IJP1,1)
      IF(NORPAR.GT.NORM) GO TO 19
      NHIP=NHIP+1
      IF(.NOT.PFAIL(IJP1)) GO TO 19
      NHIPF=NHIPF+1
   19 CONTINUE
      IF (ITP)   GO TO 210
      IF(NHIPF.GE.NHIP) GO TO 20
      TRANS(NSFROM,NSTO) =MTTFS(MFAIL,2)
      GO TO 21
   20 TRANS(NSFROM,NSTO) = MTTFS(MFAIL,1)
      GO TO 21
  210 IF(NHIPF.GE.NHIP) GO TO 211
      IF  (NTRANS(NBIN).EQ.1) TRANS(NSTO,NSFROM)  = MTTFA(MFAIL,2)
      IF  (NTRANS(NBIN).EQ.0) TRANS(NSTO,NSFROM)  = MTTRA(MFAIL,2)
      GO TO 21
  211 IF(NTRANS(NBIN).EQ.1)  TRANS(NSTO,NSFROM)  = MTTFA(MFAIL,1)
      IF(NTRANS(NBIN).EQ.0)  TRANS(NSTO,NSFROM)  = MTTRA(MFAIL,1)
   21 CONTINUE
      IF (ITP)   GO TO 220
      NSTART=NSFROM+1
      TMPSUM=0.0
      IF(NSTART.GT.NSMAX) GO TO 23
      DO 22 NSTO=NSTART,NSMAX
   22 TMPSUM=TMPSUM+TRANS(NSFROM,NSTO)
   23 TRANS(NSFROM,NSFROM)=TMPSUM
      GO TO 24
  220 TMPSUM=0.0
      DO 221 NSTO=1,NSMAX
  221 TMPSUM = TMPSUM + TRANS(NSTO,NSFROM)
      TRANS(NSFROM,NSFROM)=      -TMPSUM
   24 CONTINUE
      RETURN
      END
```

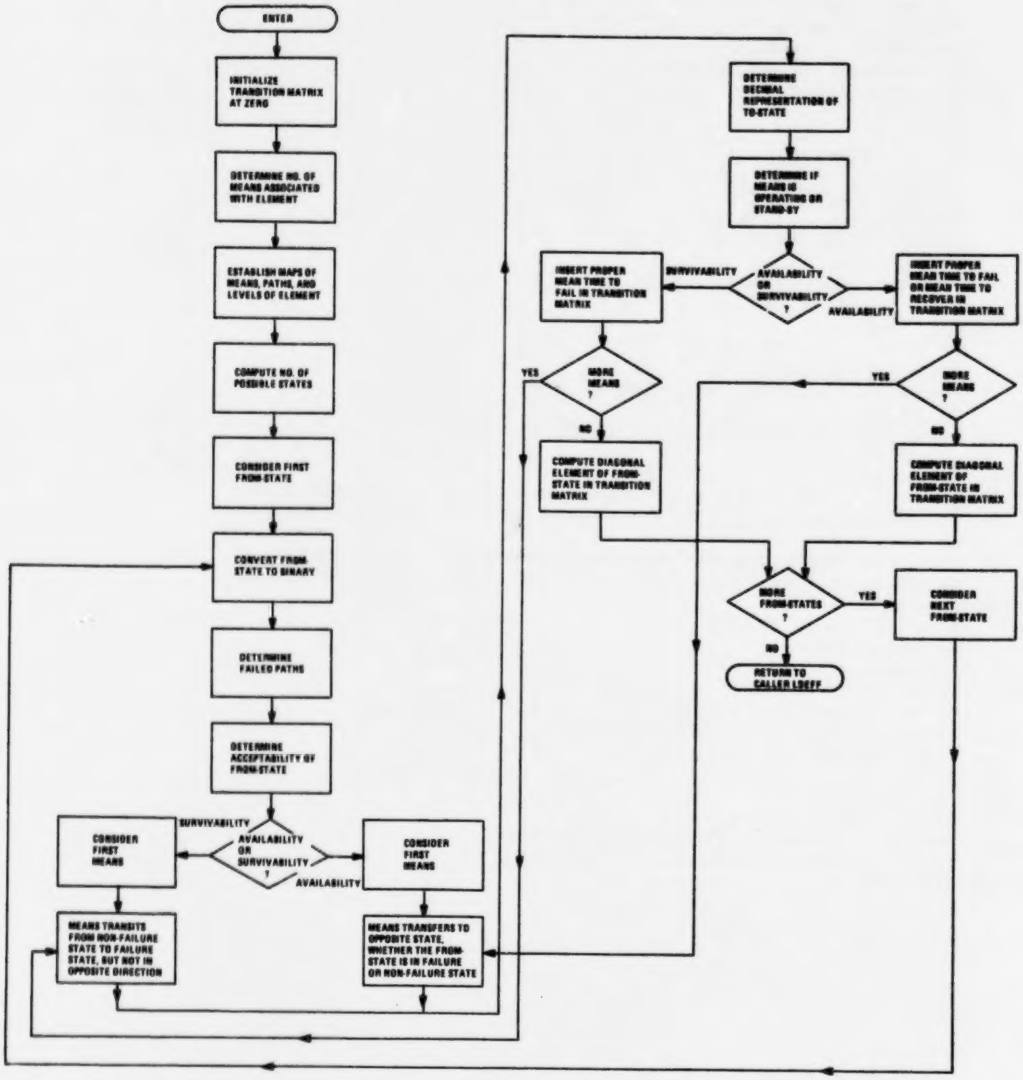

ENTER
INITIALIZE TRANSITION MATRIX AT ZERO
DETERMINE NO. OF MEANS ASSOCIATED WITH ELEMENT
ESTABLISH MAPS OF MEANS, PATHS, AND LEVELS OF ELEMENT
COMPUTE NO. OF POSSIBLE STATES
CONSIDER FIRST FROM-STATE
CONVERT FROM-STATE TO BINARY
DETERMINE FAILED PATHS
DETERMINE ACCEPTABILITY OF FROM-STATE
AVAILABILITY OR SURVIVABILITY ?
SURVIVABILITY
AVAILABILITY
CONSIDER FIRST MEANS
CONSIDER FIRST MEANS
MEANS TRANSITS FROM NON-FAILURE STATE TO FAILURE STATE, BUT NOT IN OPPOSITE DIRECTION
MEANS TRANSFERS TO OPPOSITE STATE, WHETHER THE FROM-STATE IS IN FAILURE OR NON-FAILURE STATE
DETERMINE DECIMAL REPRESENTATION OF TO-STATE
DETERMINE IF MEANS IS OPERATING OR STAND-BY
AVAILABILITY OR SURVIVABILITY ?
SURVIVABILITY
AVAILABILITY
INSERT PROPER MEAN TIME TO FAIL IN TRANSITION MATRIX
INSERT PROPER MEAN TIME TO FAIL OR MEAN TIME TO RECOVER IN TRANSITION MATRIX
MORE MEANS ?
YES
NO
MORE MEANS ?
YES
NO
COMPUTE DIAGONAL ELEMENT OF FROM-STATE IN TRANSITION MATRIX
COMPUTE DIAGONAL ELEMENT OF FROM-STATE IN TRANSITION MATRIX
MORE FROM-STATES ?
YES
NO
CONSIDER NEXT FROM-STATE
RETURN TO CALLER LDEFF

Figure 87. Flowchart of Subroutine SETUP

SUBROUTINE LPLACE

```
      SUBROUTINE LPLACE(NSMAX)
      COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40), IREAD(20),
     * MTTFA(300,2), MTTFS(300,2), MTTRA(300,2), LIST(4), COST(4),
     * MEMBER(100,2), CSTINC(100,2), SDATA(10), NDATA(10), MSYS(10,23),
     * NSAC(64), MINC(5), MPATH(5), MEMB(10), NSTATE(5), PFAIL(10),
     * PCHK(10), NTRANS(5), LEVEL(10), TRANS(64,64), AVAIL(40)
      COMMON COEF(64,64), SRV(40), PROD(65), PROB(65), NST(64),
     * NSFR(64), EFF(40)
      COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JQ, JU, JX, JY,
     * JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSEAS, TA,AACUP,BBCUP,
     *CCUP1,CCUP2,CCUP3,CCUP4,CCUP5,CCUP6,CCUP7, CCRON, A3, DBENTH,
     * ELEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NB, NINIT, NOX, MZ,
     * MY, MZY, NJUNC, NTRIB, NREA, NACC, DENOM, ESYS, TOTCST, CHECK
      COMMON/BLOCK2/TIME,NMR,DTYPE,POPT
      LOGICAL IMPL
      REAL MTTFA,MTTRA,MTTFS
C     THIS SUBROUTINE IS INTENDED TO PRODUCE THE STATE PROBABILITIES
C     THROUGH THE SOLUTION OF THE LAPLACE TRANSFORM EQUATIONS DESCRIBING
C     THE TRANSITION MATRIX.  AS PRESENTLY WRITTEN, IT WILL HANDLE THE
C     MATRICES RESULTING FROM AN EIGHT-UNIT SYSTEM (256 STATES).
      DO  8 NS=1,NSMAX
      DO  1 INDEX=1,NSMAX
    1 COEF(NS,INDEX)=0.0
      LEVEL=1
      NST (1)=NS
      PROD(1)=1.0
    2 IF(NST (LEVEL).LE.1)  GO TO 4
      NSFR  (LEVEL)=NST (LEVEL)
    3 NSFR  (LEVEL)=NSFR  (LEVEL)-1
      IF(NSFR  (LEVEL).EQ.0) GO TO 5
      NX=NSFR  (LEVEL)
      NY=NST (LEVEL)
      IF(TRANS(NX,NY).EQ.0.) GO TO 3
      PROD(LEVEL+1)=PROD(LEVEL)*TRANS(NX,NY)/(TRANS(NX,NX)-TRANS(NS,NS))
      LEVEL=LEVEL+1
      NST (LEVEL)=NSFR  (LEVEL-1)
      GO TO 2
    4 COEF(NS,NS)=COEF(NS,NS)+PROD(LEVEL)
    5 LEVEL=LEVEL-1
      IF(LEVEL.GT.0) GO TO 3
      PROB(NS)=COEF(NS,NS)/EXP(TRANS(NS,NS)*TIME)
      MAXDEX=NS-1
      IF(MAXDEX.EQ.0) GO TO 8
      DO  7 INDEX=1,MAXDEX
      DO  6 JDEX=1,MAXDEX
      IF(TRANS(JDEX,NS).EQ.0) GO TO 6
      IF(COEF(JDEX,INDEX).EQ.0) GO TO 6
      COEF(NS,INDEX)=COEF(NS,INDEX)+TRANS(JDEX,NS)*COEF(JDEX,INDEX)/
     1(TRANS(NS,NS)-TRANS(INDEX,INDEX))
    6 CONTINUE
    7 PROB(NS)=PROB(NS)+COEF(NS,INDEX)/EXP(TRANS(INDEX,INDEX)*TIME)
    8 CONTINUE
      RETURN
      END
```

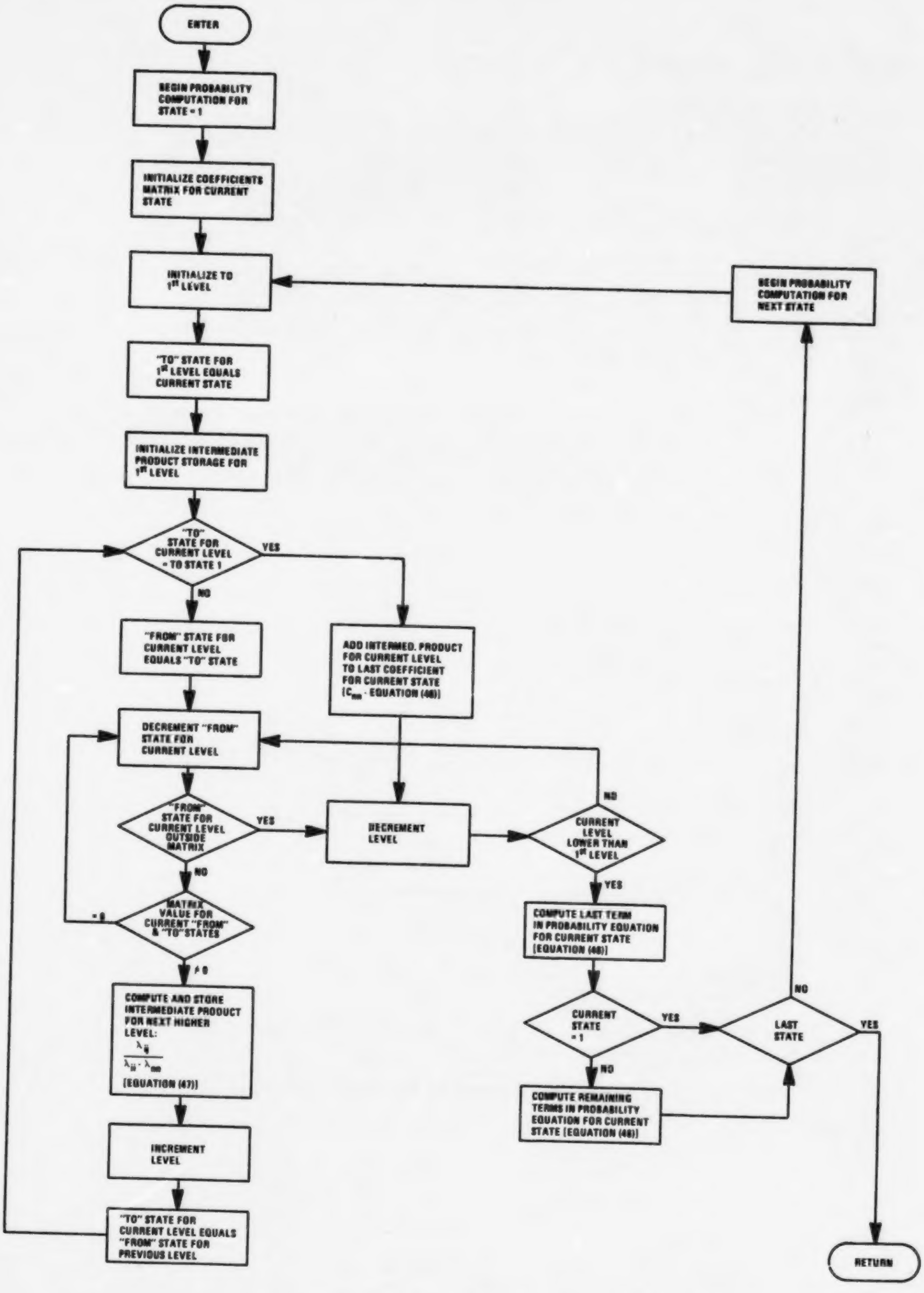

ENTER
BEGIN PROBABILITY COMPUTATION FOR STATE = 1
INITIALIZE COEFFICIENTS MATRIX FOR CURRENT STATE
INITIALIZE TO 1ST LEVEL
"TO" STATE FOR 1ST LEVEL EQUALS CURRENT STATE
INITIALIZE INTERMEDIATE PRODUCT STORAGE FOR 1ST LEVEL
"TO" STATE FOR CURRENT LEVEL = TO STATE 1
YES
NO
"FROM" STATE FOR CURRENT LEVEL EQUALS "TO" STATE
ADD INTERMED. PRODUCT FOR CURRENT LEVEL TO LAST COEFFICIENT FOR CURRENT STATE [C_{mm} - EQUATION (48)]
DECREMENT "FROM" STATE FOR CURRENT LEVEL
"FROM" STATE FOR CURRENT LEVEL OUTSIDE MATRIX
YES
NO
DECREMENT LEVEL
CURRENT LEVEL LOWER THAN 1ST LEVEL
NO
YES
MATRIX VALUE FOR CURRENT "FROM" & "TO" STATES
= 0
≠ 0
COMPUTE AND STORE INTERMEDIATE PRODUCT FOR NEXT HIGHER LEVEL: $\frac{\lambda_{ij}}{\lambda_{ii} - \lambda_{mm}}$ [EQUATION (47)]
INCREMENT LEVEL
"TO" STATE FOR CURRENT LEVEL EQUALS "FROM" STATE FOR PREVIOUS LEVEL
COMPUTE LAST TERM IN PROBABILITY EQUATION FOR CURRENT STATE [EQUATION (48)]
CURRENT STATE = 1
YES
NO
COMPUTE REMAINING TERMS IN PROBABILITY EQUATION FOR CURRENT STATE [EQUATION (48)]
LAST STATE
NO
YES
BEGIN PROBABILITY COMPUTATION FOR NEXT STATE
RETURN

Figure 88. Flowchart of Subroutine LPLACE

SUBROUTINE SOLVE

```
 SUBROUTINE SOLVE(NSMAX)
 COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40), IREAD(20),
* MTTFA(300,2), MTTFS(300,2), MTTRA(300,2), LIST(4), COST(4),
* MEMBER(100,2), CSTINC(100,2), SDATA(10), NDATA(10), MSYS(10,23)
* NSAC(64), MINC(5), MPATH(5), MEMB(10), NSTATE(5), PFAIL(10),
* PCHK(10), NTRANS(5), LEVEL(10), TRANS(64,64), AVAIL(40)
 COMMON COEF(64,64), SRV(40), PROD(65), PROB(65), NST(64),
* NSFR(64), EFF(40)
 COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JQ, JU, JX, JY,
* JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSEAS, TA,AACUP,BBCUP,
*CCUP1,CCUP2,CCUP3,CCUP4,CCUP5,CCUP6,CCUP7, CCRON, A3, DBENTH,
* ELEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NI, NINIT, NOX, MZ,
* MY, MZY, NJUNC, NTRIB, NREA, NACC, DENOM, ESYS, TOTCST, CHECK
 DIMENSION      WKAREA(256)
 REAL MTTFA,MTTRA,MTTFS
 LOGICAL IMPL
 DO 1 I=1,NSMAX
1 PROB(I) = 0.0
 PROB(NSMAX) = 1.
 DO 2 I=1,NSMAX
2 TRANS(NSMAX,I) = 1.
 CALL LEQT1F(TRANS,1,NSMAX,64,PROB,2,WKAREA,IER)
 RETURN
 END
```

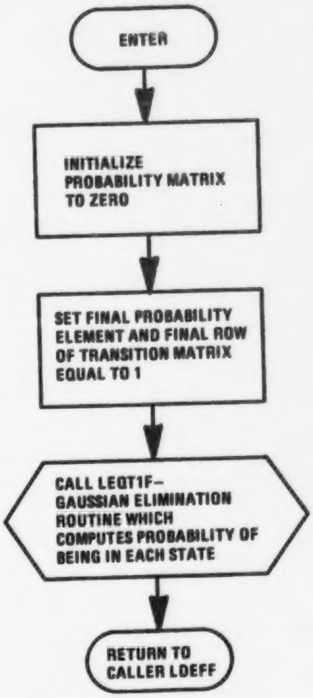

ENTER
INITIALIZE PROBABILITY MATRIX TO ZERO
SET FINAL PROBABILITY ELEMENT AND FINAL ROW OF TRANSITION MATRIX EQUAL TO 1
CALL LEQT1F— GAUSSIAN ELIMINATION ROUTINE WHICH COMPUTES PROBABILITY OF BEING IN EACH STATE
RETURN TO CALLER LDEFF

Figure 89. Flowchart of Subroutine SOLVE

SUBROUTINES LEQT1F, LVDATF, LVELMF, and VERTST

The listings for Subroutines LEQT1F, LVDATF, LVELMF and VERTST are not presented in this report to limit distribution of the IMSL proprietary subroutines. Interpreted FORTRAN IV source decks for the subroutines are supplied to the EPA with the total program source deck.

SUBROUTINE SYSEFF

```
      SUBROUTINE SYSEFF
      COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40), IREAD(20),
     * MTTFA(300,2), MTTFS(300,2), MTTRA(300,2), LIST(4), COST(4),
     * MEMBER(100,2), CSTINC(100,2), SDATA(10), NDATA(10), MSYS(10,23),
     * NSAC(64), MINC(5), MPATH(5), MEMB(10), NSTATE(5), PFAIL(10),
     * PCHK(10), NTRANS(5), LEVEL(10), TRANS(64,64), AVAIL(40)
      COMMON COEF(64,64), SRV(40), PROD(65), PROB(65), NST(64),
     * NSFR(64), EFF(40)
      COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JQ, JU, JX, JY,
     * JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSEAS, TA,AACUP,BBCUP,
     *CCUP1,CCUP2,CCUP3,CCUP4,CCUP5,CCUP6,CCUP7, CCRON, A3, DBENTH,
     * ELEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NI, NINIT, NOX, MZ,
     * MY, MZY, NJUNC, NTRIB, NREA, NACC, DENOM, ESYS, TOTCST, CHECK
      COMMON/BLK/ MASK(20)
C
C     THIS SUBROUTINE COMPUTES THE TOTAL SYSTEM EFFECTIVENESS FOR THE
C     RIVER BASIN MONITORING SYSTEM.  REQUIRED INPUT DATA ARE THE
C     ELEMENT PRIORITIES, THE VIOLATION DURATIONS, THE ELEMENT
C     EFFECTIVENESSES AND THE SYSTEM IMPLEMENTATION SCHEME.  AS
C     PROGRAMMED, IT WILL HANDLE A MAXIMUM OF 40 SEGMENTS AND 20
C     PARAMETERS.
C
      LOGICAL IMPL, MASK
      ESYS = 0.0
      DO 10 I=1,NREA
      ESYS = ESYS + EFF(I)
   10 CONTINUE
      ESYS=ESYS/DENOM
      PRINT 20,ESYS
   20 FORMAT (1H1,//10X,* SYSTEM EFFECTIVENESS = *,E13.5)
      RETURN
      END
```

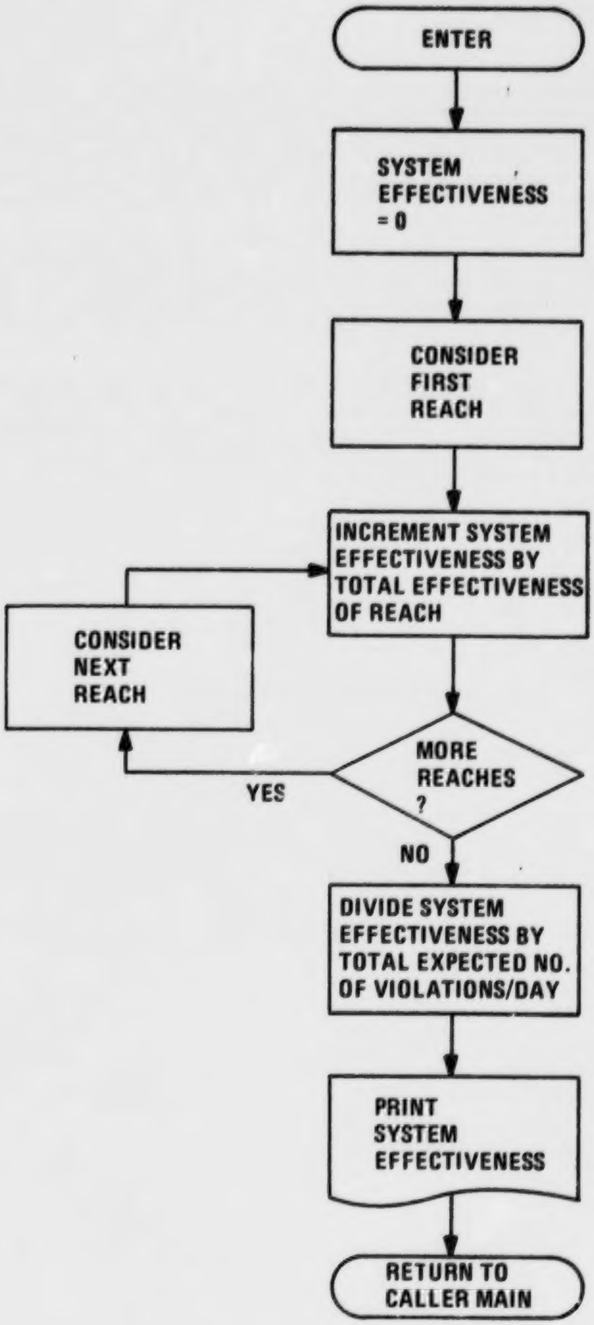

ENTER
SYSTEM EFFECTIVENESS = 0
CONSIDER FIRST REACH
INCREMENT SYSTEM EFFECTIVENESS BY TOTAL EFFECTIVENESS OF REACH
CONSIDER NEXT REACH
MORE REACHES ?
YES
NO
DIVIDE SYSTEM EFFECTIVENESS BY TOTAL EXPECTED NO. OF VIOLATIONS/DAY
PRINT SYSTEM EFFECTIVENESS
RETURN TO CALLER MAIN

Figure 90. Flowchart of Subroutine SYSEFF

SUBROUTINE CALCST

```
      SUBROUTINE CALCST
      COMMON CAP(40,20),VIOLSS(40,20), NVAR(20), IMPL(40), IREAD(20),
     * MTTFA(300,2), MTTFS(300,2), MTTRA(300,2), LIST(4), COST(4),
     * MEMBER(100,2), CSTINC(100,2), SDATA(10), NDATA(10), MSYS(10,23),
     * NSAC(64), MINC(5), MPATH(5), MEMB(10), NSTATE(5), PFAIL(10),
     * PCHK(10), NTRANS(5), LEVEL(10), TRANS(64,64), AVAIL(40)
      COMMON COEF(64,64), SRV(40), PROD(65), PROB(65), NST(64),
     * NSFR(64), EFF(40)
      COMMON/BLOCK1/ NR, FINL, IA, II, IOPT, JA, JJ, JQ, JU, JX, JY,
     * JZ, NJ, NPAR, IRUN, NUM, QUP, NZ, NT, NSEAS, TA,AACUP,BBCUP,
     *CCUP1,CCUP2,CCUP3,CCUP4,CCUP5,CCUP6,CCUP7, CCRON, A3, DBENTH,
     * ELEV, CSAT, VALMIS, MON, NYEAR, CACT, KK, NI, NINIT, NOX, MZ,
     * MY, MZY, NJUNC, NTRIB, NREA, NACC, DENOM, ESYS, TOTCST, CHECK
      COMMON/BLK/MASK(40)
      INTEGER CARD
      DATA NEND/5HEND  /,NGRP/5HCOSTG/,NCST/5HCOSTM/
      LOGICAL LIST,MASK,TEST
   33 TOTCST = 0.0
    1 READ (5 ,201) CARD, IDN,(COST(N),N=1,4),IGROUP
  201 FORMAT (A5,I5,4F10.0,I5)
      IF (CARD.EQ.NEND) GO TO 6
      IF (CARD.EQ.NGRP) GO TO 3
      IF (CARD.EQ.NCST) GO TO 2
      GO TO 11
    2 IF (IGROUP.LE.0) GO TO 11
      MEMBER(IDN,1) = IGROUP
      CSTINC(IDN,1) = COST(1) +COST(2) + COST(3) -COST(4)
  109 FORMAT (E14.2)
      GO TO 1
    3 IF (IGROUP) 11,4,5
    4 IF (IDN.NE.1) GO TO 11
    5 MEMBER(IDN,2) = IGROUP
      CSTINC(IDN,2) = COST(1) + COST(2) +COST(3) -COST(4)
      GO TO 1
    6 IF (MEMBER(1,2).NE.0) GO TO 11
      DO 10 M=1,100
      INTEG = 1 + (M-1)/32
      IBIT = M - (INTEG-1)*32
      TEST = LIST(INTEG).AND.MASK(IBIT)
      IF (TEST) 20,10
   20 INDEX = MEMBER(M,1)
      IF (INDEX.LE.0) GO TO 11
      TOTCST = TOTCST + CSTINC(M,1)
    7 IF (MEMBER(INDEX,2)) 10,8,9
    8 IF (INDEX.NE.1) GO TO 11
    9 TOTCST = TOTCST + CSTINC(INDEX,2)
      MEMBER(INDEX,2) = -MEMBER(INDEX,2)
      INDEX = -MEMBER(INDEX,2)
      IF (INDEX.NE.0) GO TO 7
   10 CONTINUE
      RETURN
   11 WRITE (NJ,301)
  301 FORMAT (1H1,46HERRORIN COST DATA DECK. EXECUTION TERMINATED.
      STOP 700
      END
```

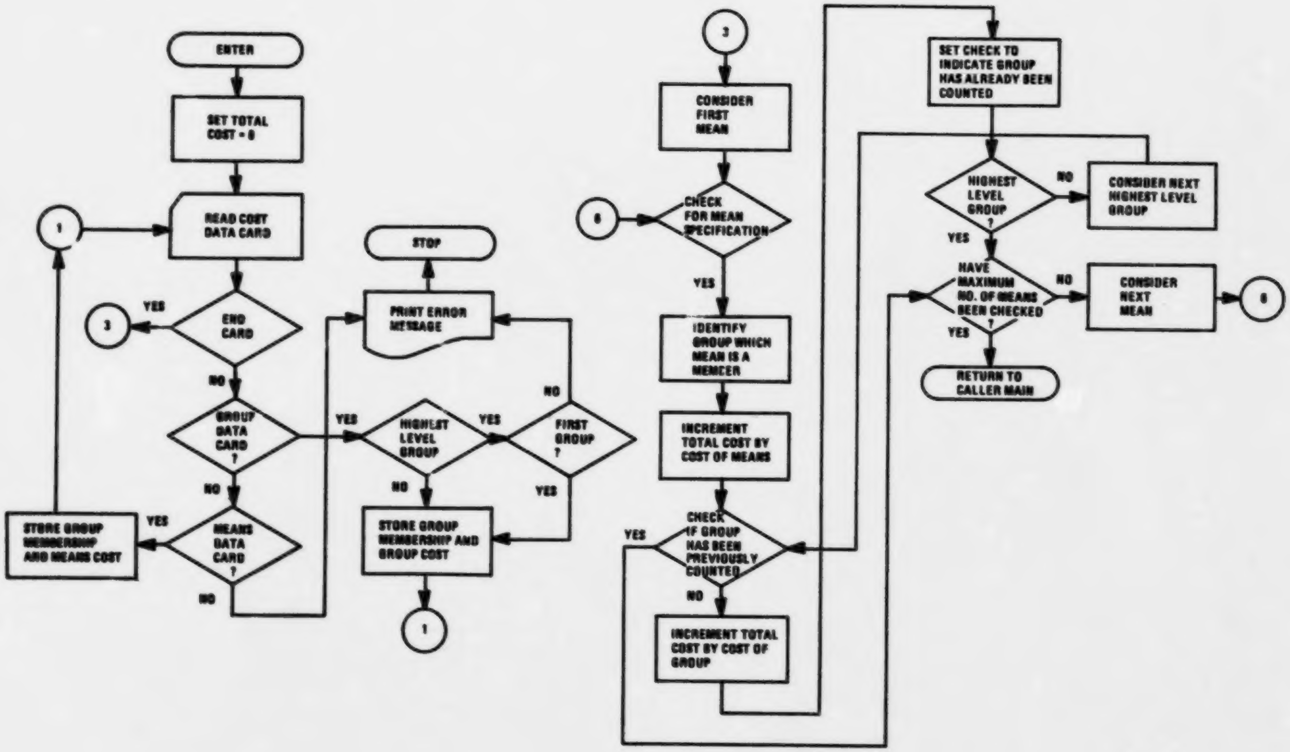

ENTER
SET TOTAL COST = 0
READ COST DATA CARD
1
END CARD
YES
3
NO
GROUP DATA CARD ?
YES
NO
MEANS DATA CARD ?
YES
STORE GROUP MEMBERSHIP AND MEANS COST
NO
HIGHEST LEVEL GROUP
YES
FIRST GROUP ?
NO
YES
NO
PRINT ERROR MESSAGE
STOP
STORE GROUP MEMBERSHIP AND GROUP COST
1
3
CONSIDER FIRST MEAN
6
CHECK FOR MEAN SPECIFICATION
YES
IDENTIFY GROUP WHICH MEAN IS A MEMCER
INCREMENT TOTAL COST BY COST OF MEANS
CHECK IF GROUP HAS BEEN PREVIOUSLY COUNTED
YES
NO
INCREMENT TOTAL COST BY COST OF GROUP
SET CHECK TO INDICATE GROUP HAS ALREADY BEEN COUNTED
HIGHEST LEVEL GROUP ?
NO
CONSIDER NEXT HIGHEST LEVEL GROUP
YES
HAVE MAXIMUM NO. OF MEANS BEEN CHECKED ?
NO
CONSIDER NEXT MEAN
6
YES
RETURN TO CALLER MAIN

Figure 91. Flowchart of Subroutine CALCST

APPENDIX G

COMPUTER LISTINGS FOR DEMONSTRATION CANDIDATES

Presented in this appendix are the listings of the input data decks and the resulting printed output for analysis of the various demonstration candidates. The listing of the input data deck for each candidate is presented first, followed immediately by the associated output from the design analysis program. The exception to this approach is the Preliminary Design case. The output of the computer analysis for preliminary design is presented in Section VIII. The entire RIBAM Standard Data Deck is printed only once, since it is the same for each candidate. The listing of the RIBAM Standard Data Deck is presented first.

RIBAM STANDARD DATA DECK

```
FILE A                BEAVER RIVER BASIN ANALYSIS - SEPTEMBER 1970
ENDFILE A
FILE B        03         02        38         05        1182.
ENDFILE B
FILE C      01        01 02 03 04 05 06 07 08 09 10
FILE C      02        11 12
FILE C      03        13 14 15 16 17 18 19 20
FILE C      04        21 22 23 24 25 26 27 28 29 30 31
FILE C      05        32 33 34 35 36 37 38
ENDFILE C
FILE D                01       01        02        04
FILE D                02       04        03        05
ENDFILE D
FILE E-1        01     120.                                  0.5
FILE E-1        02     40.
FILE E-1        03     30.
ENDFILE E-1                                                  .3
FILE E-2        01     4.5               420.
FILE E-2        02     1.1               155.
FILE E-2        03     1.1               150.
ENDFILE E-2
FILE E-3        01     26.               .7                  3.0
FILE E-3        02     18.               .15                 1.5
FILE E-3        03     13.               .04                 .5
ENDFILE E-3
FILE E-4        01                                           1.5
FILE E-4        02                                           1.5
FILE E-4        03                       .004                2.0
ENDFILE E-4
FILE E-5        01                       .2                  1.3
FILE E-5        02                       .1                  .5
FILE E-5        03                       .1                  .5
ENDFILE E-5
FILE E-6        01                       7.0
FILE E-6        02                       7.0
FILE E-6        03                       8.5
ENDFILE E-6
FILE F-1        01      1.0      88.0    .119526   .51326    11.0       .192
FILE F-1        02     15.0     87.0     .119526   .51326   23.2
FILE F-1        03      2.0      72.0    .119526   .51326   123.2
FILE F-1        04      8.0      70.0    .119526   .51326     0.0
FILE F-1        05      7.0      62.0    .119526   .51326    16.9
FILE F-1        06      8.0      55.0    .13443    .41952    88.8     0.647
FILE F-1        07      5.0      47.0    .13443    .41952   18.45     .0508
FILE F-1        08      5.0      42.0    .13443    .41952   1.8       75.1
FILE F-1        09      2.0      37.0    .112      .406     1.2       124.57
FILE F-1        10      4.0      35.0    .138      .303      4.2
FILE F-1        11      5.5      12.0    .12412    .38799
FILE F-1        12      6.5       6.5    .12412    .38799
FILE F-1        13      3.2      54.4    .06925    .48418
FILE F-1        14      2.4      51.2    .06925    .48418
FILE F-1        15      1.4      48.8    .06925    .48418               .3
FILE F-1        16      2.6      47.4    .06925    .48418   31.0       141.2
FILE F-1        17      2.4      44.8    .06925    .48418   19.87       3.42
FILE F-1        18      5.6      42.4    .06925    .48418   2.0
FILE F-1        19     12.0      36.8    .06925    .48418   21.1        .23
FILE F-1        20      3.2      24.8    .06925    .48418   126.6     2.77
FILE F-1        21      3.0      31.0    .067      .315     18.9      252.0
FILE F-1        22      3.0      28.0    .071      .330      4.1       84.7
FILE F-1        23      1.5      25.0    .056      .343                .34
FILE F-1        24      2.0      23.5    .078      .364               208.67
FILE F-1        25      2.0      21.5    .045      .463     16.1
FILE F-1        26      1.0      19.5    .096      .318     18.2      1.09
FILE F-1        27     2.0      18.5     .212      .217      3.7      0.18
FILE F-1       28    1.0       16.5     .084      .393                 86.1
FILE F-1       29    3.0       15.5     .075      .431                362.7
FILE F-1       30    8.0       12.5     .136      .336      4.14
FILE F-1       31    4.5       4.5      .02959    .60960
FILE F-1       32     1.8       21.6    .05046    .54204   9.5        12.3
FILE F-1       33     7.2       19.8    .05046    .54204    2.5
FILE F-1       34     1.8       12.6    .05046    .54204   133.8
FILE F-1       35     3.0       10.8    .00801    .67583              0.10
FILE F-1       36     4.0        7.8    .00801    .67583              5.15
FILE F-1       37     2.0        3.8    .00801    .67583    4.9        .28
FILE F-1       38     1.8        1.8    .00801    .67583               .09
ENDFILE F-1
FILE F-2       01    4.3         02          5.026   .969   1.673
FILE F-2       2                 02          5.026   .969   1.673
FILE F-2       3                 02          5.026   .969   1.673
FILE F-2       4                 02          5.026   .969   1.673
FILE F-2       5      .12        02          5.026   .969   1.673
FILE F-2       6     .77         02          5.026   .969   1.673
FILE F-2       7      .051       02          5.026   .969   1.673
FILE F-2       8                 02          5.026   .969   1.673
FILE F-2       9                 02          5.026   .969   1.673
FILE F-2       10    15.7        02          5.026   .969   1.673
FILE F-2       11                02          5.026   .969   1.673
FILE F-2       12       .4       02          5.026   .969   1.673
FILE F-2       13                02          5.026   .969   1.673
FILE F-2       14       .9       02          5.026   .969   1.673
FILE F-2       15     3.8        02          5.026   .969   1.673
FILE F-2       16     2.7        02          5.026   .969   1.673
FILE F-2       17     1.23       02          5.026   .969   1.673
FILE F-2       18     0.2        02          5.026   .969   1.673
FILE F-2       19                02          5.026   .969   1.673
FILE F-2       20                02          5.026   .969   1.673
FILE F-2       21    3.7         02          5.026   .969   1.673
FILE F-2       22    .46         02          5.026   .969   1.673
FILE F-2       23    3.1         02          5.026   .969   1.673
FILE F-2       24                02          5.026   .969   1.673
FILE F-2       25                02          5.026   .969   1.673
FILE F-2       26    43.9        02          5.026   .969   1.673
FILE F-2       27                02          5.026   .969   1.673
FILE F-2       28    2.9         02          5.026   .969   1.673
FILE F-2       29    2.5         02          5.026   .969   1.673
FILE F-2       30     .26        02          5.026   .969   1.673
FILE F-2       31    7.7         02          5.026   .969   1.673
FILE F-2       32                02          5.026   .969   1.673
FILE F-2       33    0.2         02          5.026   .969   1.673
FILE F-2       34                02          5.026   .969   1.673
FILE F-2       35    0.23        02          5.026   .969   1.673
FILE F-2       36                02          5.026   .969   1.673
FILE F-2       37    3.1         02          5.026   .969   1.673
FILE F-2       38    1.8         02          5.026   .969   1.673
ENDFILE F-2
FILE F-3       02         1      2.2                       DEER,BEECH,MILL CR.
FILE F-3       01         1      2.3                       ALLIANCE STP
FILE F-3       03         1      2.1                       BELOW BERLIN DAM
FILE F-3       04         1      1.9                       LAKE MILTON
FILE F-3       05         1      1.7                       MILTON STP,KALE CR.
FILE F-3       06         1      2.0                       WEST BRANCH-MAHONING
FILE F-3       07         1      2.3                       EAGLE,DUCK CREEK
FILE F-3       08         1      2.3                       C"WELD + PITTS STEEL
FILE F-3       09         1      4.5                       REPUBLIC STEEL
FILE F-3       10         1      5.0                       WARREN STP, MUD CR.
FILE F-3       11         1      2.3                       BELOW MOSQUITO RES.
FILE F-3       12         1      2.3                       HOWLAND STP
FILE F-3       13         1      2.7                       BELOW SHENANGO RES.
FILE F-3       14         1      2.7                       SHARPSVILLE STP
FILE F-3       15         1      2.7                       SHARON STP
FILE F-3        16         1    2.7                       YANKEE RUN+SHARON ST
FILE F-3        17         1    2.7                       HOGBACK RUN
FILE F-3        18         1    2.7                       WEST MIDDLESEX STP
FILE F-3        19         1    2.7                       DEER CREEK
FILE F-3        20         1    2.7                       NESHANNOCK CREEK
FILE F-3        21         1    7.0                       NILES ELEC.,STP,MEA
FILE F-3        22         1    5.5                       MCDONALD STP+STEEL
FILE F-3        23         1    6.0                       GIRARD STP
FILE F-3        24         1    3.5                       YOUNGS. SHEET+STEEL
FILE F-3        25         1    4.8                       MILL CREEK
FILE F-3        26         1    5.0                       YOUNGS. STP,CRAB CR.
FILE F-3        27         1    3.0                       DRY RUN
FILE F-3        28         1    2.5                       REPUBLIC STEEL
FILE F-3        29         1    4.5                       YOUNGS. SHEET+TUBE
FILE F-3        30         1    4.5                       LOWELLVILLE STP
FILE F-3        31         1    2.0                       NEWCASTLE STP
FILE F-3        32         1    2.1                       PENN POWER CO.
FILE F-3        33         1    2.2                       WAMPOM STP
FILE F-3        34         1    2.2                       CONNOQUENNESSING CR.
FILE F-3        35         1     2.5                      KOPPEL STP
FILE F-3        36         1    2.8                       BABCOCK + WILCOX
FILE F-3        37         1    3.1                       BEAVER FALLS STP
FILE F-3        38         1    3.1                       NEW BRIGHTON STP
ENDFILE F-3
FILE F-4        01    100.      9.8                          .2        7.2
FILE F-4        01     180.
FILF F-4        02    100.                                   .2
FILE F-4         2
FILE F-4        03     90.                                   .1
FILE F-4         3
FILE F-4        04                                           .2
FILE F-4         4
FILE F-4        05     120.
FILE F-4         5     120.    -66767.                                 35.
FILE F-4        06     60.
FILE F-4         6     100.
FILE F-4        07     100.
FILE F-4         7     100.    11926.                                  1136.
FILE F-4        08     60.      7.66                                    .42
FILE F-4         8
FILE F-4        09     150.     10.8               0.0007               32.05
FILE F-4         9
FILE F-4        10     150.
FILE F-4        10     150.
FILE F-4        11
FILE F-4        11
FILE F-4        12
FILE F-4        12     100.
FILE F-4        13
FILE F-4        13                                                     182.
FILE F-4        14
FILE F-4        14     50.
FILE F-4        15              53.6                                    0.22
FILE F-4        15     50.
FILE F-4        16     150.     2.61        .27    0.23         1.25   17.95
FILE F-4        16     100.
FILE F-4        17     60.      59.3               0.198               69.44
FILE F-4        17     100.
FILE F-4        18     60.
FILE F-4        18     100.
FILE F-4        19     60.
FILE F-4        19
FILE F-4        20     60.                                              .8
FILE F-4        20             -31989.
FILE F-4        21     200.     9.92                                   .067
FILE F-4        21     100.    73226.                                 -24683.
FILE F-4         22     120.      7.45                                    1.48
FILE F-4         22     100.
FILE F-4         23
FILE F-4         23     100.
FILE F-4         24               7.45                .01                 1.37
FILE F-4         24
FILE F-4         25     180.
FILE F-4         25
FILE F-4         26     120.                          0.016                0.022
FILE F-4         26     120.
FILE F-4         27     150.     2967.                                     157.
FILE F-4         27
FILE F-4         28               37.72                                   21.5
FILE F-4         28      80.
FILE F-4         29                8.14               .024                9.37
FILE F-4         29      80.     57682.
FILE F-4         30     150.
FILE F-4         30     150.
FILE F-4         31     150.
FILE F-4         31     150.
FILE F-4         32     150.      150.                 .7
FILE F-4         32
FILE F-4         33      80.
FILE F-4         33     100.      421.                                   -57719.
FILE F-4         34     190.                .5
FILE F-4         34
FILE F-4         35               120.                                     2.6
FILE F-4         35     150.
FILE F-4         36              85.                                      54.8
FILE F-4         36               -19663.                                  139.
FILE F-4         37      150.    21.4                 .007                32.3
FILE F-4         37     150.
FILE F-4         38               150.                                    37.4
FILE F-4         38     120.      69929.                                  1279.
ENDFILE F-4
FILE F-5          1     2.6       .05       520.
FILE F-5         01     4.5       .38       420.      117.
FILE F-5          2     1.4
FILE F-5         02      2.1                360.
FILE F-5          3     1.4                 280.
FILE F-5         03      2.1                320.
FILE F-5         04
FILE F-5          4
FILE F-5         05     1.4                 560.
FILE F-5          5     22.       1685.     500.
FILE F-5         06     1.4                 300.      250.
FILE F-5          6     22.                 550.
FILE F-5         07     1.4                 300.
FILE F-5          7     22.                 500.
FILE F-5         08     1.4       .01       300.      27.6
FILE F-5          8
FILE F-5         09     1.6       .77       360.      53.3                 .16
FILE F-5          9
FILE F-5         10     1.4                 300.
FILE F-5         10     14.                 620.
FILE F-5         11
FILE F-5         11
FILE F-5         12
FILE F-5         12     22.                 500.
FILE F-5         13     .1
FILE F-5         13
FILE F-5         14
FILE F-5         14     22.                 500.
FILE F-5         15
FILE F-5         15     33.                 520.
FILE F-5         16     .9        .41       395.      27.5                0.23
FILE F-5          16    22                  500.
FILE F-5          17    .9                  320.     139.
FILE F-5          17    22.                 500.
FILE F-5          18    .9                  320.
FILE F-5          18    22.                 500.
FILE F-5          19    .9                  320.
FILE F-5          19
FILE F-5          20    .9                  320.     640.
FILE F-5          20                               -30095.
FILE F-5          21    1.0      1.96       400.     25.4                        0.002
FILE F-5          21    22.     -2878.      500.
FILE F-5          22    1.5                 320.     25.3
FILE F-5          22    22.                 500.
FILE F-5          23                                 2000.
FILE F-5          23    22.      2539.      500.   286339.
FILE F-5          24                                 17.1
FILE F-5          24
FILE F-5          25    1.5                 420.
FILE F-5          25
FILE F-5          26    1.5      4.14       320.     88.5
FILE F-5          26     6.                 580.
FILE F-5          27    1.5                 320.      5.0
FILE F-5          27
FILE F-5          28                                 26.4                        .22
FILE F-5          28    22.                 660.
FILE F-5          29             1.23                55.2                        .003
FILE F-5          29    22.     -3280.      650.     29.
FILE F-5          30    1.4                 320.
FILE F-5          30    22.                 500.
FILE F-5          31
FILE F-5          31    11.                 470.
FILE F-5          32    1.4      .4         320.
FILE F-5          32
FILE F-5          33    1.0                 315.
FILE F-5          33    41.                 740.   156942.
FILE F-5          34    1.8                 320.
FILE F-5          34
FILE F-5          35
FILE F-5          35    22.                 400.
FILE F-5          36
FILE F-5          36                                57551.
FILE F-5          37    1.4                 320.     36.9
FILE F-5          37    32.                 320.
FILE F-5          38                                 48.0
FILE F-5          38    32.                 320.    67493.
ENDFILE F-5
FILE F-6          01    26.      2.28       1.2      .13        3.0       .05
FILE F-6           1    30.     -94.        6.9                 21.4
FILE F-6          02    30.                 .2                  1.5
FILE F-6           2
FILE F-6          03    30.                 .2                  1.5
FILE F-6           3            -4178.
FILE F-6          04
FILE F-6           4
FILE F-6          05    21.                 .06                 1.5
FILE F-6           5    30.     10428.      6.9      88.        21.4      105.
FILE F-6          06    30.                 .1       5.0        1.5
FILE F-6           6    60.                 6.9                 21.4
FILE F-6          07    25.                  .6                 1.5
FILE F-6           7    30.     -715.       6.9     -183.       21.4      -104.
FILE F-6          08    30.      .48        .5       2.83       1.5
FILE F-6           8
FILE F-6          09    30.      9.78       .2       .01        1.5       1.95
FILE F-6           9
FILE F-6          10    30.                 .2                  1.5
FILE F-6          10    90.                 4.0                 13.0
FILE F-6      11
FILE F-6      11
FILE F-6      12
FILE F-6      12     30.                  6.9                 21.4
FILE F-6      13
FILE F-6      13
FILE F-6      14
FILE F-6      14     84.                  7.                   7.0
FILE F-6      15               11.2
FILE F-6      15     180.                 3.                  30.
FILE F-6      16     50.       11.4       .5        .017      .8        .41
FILE F-6      16     30.                  6.9                 21.4
FILE F-6      17     30.                  .2        0.034     .5
FILE F-6      17     30.                  6.9                 21.4
FILE F-6      18     30.                  .2                  .5
FILE F-6      18     110.                 13.                  8.0
FILE F-6      19     30.                  .2                  .5
FILE F-6      19
FILE F-6      20     25.       32.        .2                  .5
FILE F-6      20              -27195.              -211.
FILE F-6      21     45.        .96       .2        .05       .5        1.91
FILE F-6      21     50.      -4427.      6.9      -1291.     21.4     -4145.
FILE F-6      22     30.        .18       .5                  1.5
FILE F-6      22     50.                  6.9                 21.4
FILE F-6      23
FILE F-6      23     50.        2413.     6.9       217.      21.4     -67.
FILE F-6      24                6.91                0.022               .66
FILE F-6      24
FILE F-6      25     40.                  1.5                 1.5
FILE F-6      25                3539.              -834.
FILE F-6      26     50.                  .5         2.35     1.5       .66
FILE F-6      26     90.                  7.                  2.4
FILE F-6      27     50.                  .5                  1.5
FILE F-6      27
FILE F-6      28                62.5                                    4.08
FILE F-6      28     50.                  6.9                 21.4
FILE F-6      29                 12.3                0.092              1.28
FILE F-6      29     50.        52369.    6.9      -1240.     21.4     -361.
FILE F-6      30     30.                  .2                  1.5
FILE F-6      30     30.                  6.9                 21.4
FILE F-6      31
FILE F-6      31     60.                  4.0                 10.
FILE F-6      32     30.                  .2                  1.5
FILE F-6      32
FILE F-6      33     30.                  .4                  1.8
FILE F-6      33     10.      -27010.     16.       640.      40.
FILE F-6      34     50.                  .8                  2.
FILE F-6      34
FILE F-6      35                40.
FILE F-6      35     30.                  6.9                 21.4
FILE F-6      36                42.
FILE F-6      36                                   -14.
FILE F-6      37     30.                  .8                  1.5
FILE F-6      37     100.                 6.9                 30.
FILE F-6      38
FILE F-6      38     30.        6379.     6.9      -396.      20.
ENDFILE F-6
FILE F-7      01                                     2.27     2.5       17.3
FILE F-7       1                                              35.
FILE F-7      02                                              2.5
FILE F-7       2
FILE F-7      03                                              2.5
FILE F-7       3
FILE F-7      04
FILE F-7       4
FILE F-7      05                                              2.5
FILE F-7         5                          48.2    10.      710.
FILE F-7        06                                  2.5
FILE F-7         6                                  15.
FILE F-7        07                                  2.5
FILE F-7         7                          26.2    70.      796.
FILE F-7        08                         .002     2.5
FILE F-7         8
FILE F-7        09           .071           .324    2.5
FILE F-7         9
FILE F-7        10                                  1.5
FILE F-7        10                                  93.
FILE F-7        11
FILE F-7        11
FILE F-7        12
FILE F-7        12                                  121.
FILE F-7        13
FILE F-7        13                          7.27             545.
FILE F-7        14
FILE F-7        14                                  50.
FILE F-7        15            0.01
FILE F-7        15                                  25.
FILE F-7        16           .03            .0014   5.       .2
FILE F-7        16                                  137.
FILE F-7        17                                  1.5
FILE F-7        17                                  205.
FILE F-7        18                                  1.5
FILE F-7        18                                  135.
FILE F-7        19                                  1.5
FILE F-7        19
FILE F-7        20                                  1.5      4.8
FILE F-7        20                          3.3              4932.
FILE F-7        21           .012           .002    2.5
FILE F-7        21                          27.5    60.      5268.
FILE F-7        22                                  2.
FILE F-7        22                                  75.
FILE F-7        23                                           250.0
FILE F-7        23                         -3.7     100.
FILE F-7        24           .112           .060               2.16
FILE F-7        24
FILE F-7        25                                  2.
FILE F-7        25
FILE F-7        26                            0.012 2.
FILE F-7        26                                  123.
FILE F-7        27                                  2.
FILE F-7        27
FILE F-7        28           .578           .71                7.77
FILE F-7        28                                  85.
FILE F-7        29            .06             0.057
FILE F-7        29           -54.1         -173.9   90.      30836.
FILE F-7        30                                  2.0
FILE F-7        30                                  115.
FILE F-7        31
FILE F-7        31                                  40.
FILE F-7        32                                  2.0
FILE F-7        32
FILE F-7        33                                  2.0
FILE F-7        33                          -4.07   255.    -18909.
FILE F-7        34                                  5.0
FILE F-7        34
FILE F-7        35
FILE F-7        35                                  50.
FILE F-7        36                            0.1
FILE F-7        36                          -56.4            16665.
FILE F-7        37                          .043    2.0      5.36
FILE F-7        37                                  70.
FILE F-7        38                           7.5             41.0
FILE F-7          38                                  46.1      225.      -7115.
ENDFILE F-7
FILE F-8           1                        .2                  1.3
FILE F-8           1                        .2                  .3
FILE F-8           2                        .1                  .5
FILE F-8           2
FILE F-8           3                        .1                  .5
FILE F-8           3
FILE F-8          04
FILE F-8          04
FILE F-8           5                        .1                  .5
FILE F-8           5                        .2        429.      .3        130.
FILE F-8           6                        .1                  .5
FILE F-8           6                        2.                  .3
FILE F-8           7    700.                .1                  .5
FILE F-8           7                        .2        4.        3.        141.
FILE F-8           8              95.       .1                  .5        .009
FILE F-8           8
FILE F-8           9              246.      .1                  1.3       .039
FILE F-8           9
FILE F-8          10                        .1                  .5
FILE F-8          10                        .2                  .3
FILE F-8          11
FILE F-8          11
FILE F-8          12
FILE F-8          12                        .2                  .3
FILE F-8          13
FILE F-8          13
FILE F-8          14
FILE F-8          14                        .2                  4.0
FILE F-8          15
FILE F-8          15                        2.0                 0.9
FILE F-8          16                        .05                 0.9
FILE F-8          16                        .2                  .3
FILE F-8          17                        .1                  .5
FILE F-8          17                        .2                  .3
FILE F-8          18                        .1                  .5
FILE F-8          18                        .08                 1.0
FILE F-8          19                        .1                  1.0
FILE F-8          19
FILE F-8          20                        .1        .067      1.0       .402
FILE F-8          20
FILE F-8          21                        .1                  .5        .054
FILE F-8          21                        .2        -297.     .3        1334.
FILE F-8          22                        .1                  .9
FILE F-8          22                        .2                  .3
FILE F-8          23
FILE F-8          23                        .2        396.      .3
FILE F-8          24                                                      .222
FILE F-8          24
FILE F-8          25                        .1                  .9
FILE F-8          25
FILE F-8          26              14.6      .1                  .9        3.48
FILE F-8          26                        .4                  2.3
FILE F-8          27                        .1                  .9
FILE F-8          27
FILE F-8          28
FILE F-8          28                        .1                  .3
FILE F-8          29                                                      .128
FILE F-8          29                        .2                  .3        -959.
FILE F-8          30                        .1                  .5
FILE F-8          30                        .2                  .3
FILE F-8          31
FILE F-8          31                        .08                 .8
FILE F-8          32                        .1                  .5        .4
FILE F-8          32
FILE F-8    33                 .03                .1
FILE F-8    33                 .2                 .5
FILE F-8    34                 .5                 1.3
FILE F-8    34
FILE F-8    35
FILE F-8    35                 .2                 .3
FILE F-8    36
FILE F-8    36
FILE F-8    37                 .1                 .5
FILE F-8    37                 .1                 .2
FILE F-8    38
FILE F-8    38                 .13                .8
ENDFILE F-8
FILE F-9    01                 2.0
FILE F-9    01                 3.7
FILE F-9    02                 7.
FILE F-9     2
FILE F-9    03                 7.
FILE F-9     3
FILE F-9    04
FILE F-9     4
FILE F-9    05                 7.
FILE F-9     5                 5.0    -1254.
FILE F-9    06                 6.
FILE F-9     6                 2.8
FILE F-9    07                 6.
FILE F-9     7                 1.0    19.
FILE F-9    08                 6.
FILE F-9     8
FILE F-9    09                 6.
FILE F-9     9
FILE F-9    10                 6.
FILE F-9    10                 7.2
FILE F-9    11
FILE F-9    11
FILE F-9    12
FILE F-9    12                 7.0
FILE F-9    13
FILE F-9    13
FILE F-9    14
FILE F-9    14                 7.0
FILE F-9    15
FILE F-9    15                 2.0
FILE F-9    16                 2.6
FILE F-9    16                 2.0
FILE F-9    17                 7.0
FILE F-9    17                 7.0
FILE F-9    18                 7.0
FILE F-9    18                 7.0
FILE F-9    19                 7.0
FILE F-9    19
FILE F-9    20                 7.0
FILE F-9    20                        -5135.
FILE F-9    21                 7.
FILE F-9    21                 6.0    -5840.
FILE F-9    22                 7.
FILE F-9    22                 1.5
FILE F-9    23
FILE F-9    23                 2.5    -628.
FILE F-9    24
FILE F-9    24
FILE F-9    25                 7.0
FILE F-9    25
FILE F-9    26                 7.0
FILE F-9    26                 7.1
FILE F-9    27                 7.
FILE F-9        27
FILE F-9        28
FILE F-9        28                        7.0
FILE F-9        29
FILE F-9        29                        1.5       -1656.
FILE F-9        30                        7.
FILE F-9        30                        4.5
FILE F-9        31
FILE F-9        31                        7.0
FILE F-9        32                        7.
FILE F-9        32
FILE F-9        33                        7.
FILE F-9        33                        7.0       3035.
FILE F-9        34                        5.5
FILE F-9        34
FILE F-9        35
FILE F-9        35                        6.0
FILE F-9        36
FILE F-9        36                                  -6144.
FILE F-9        37                        7.
FILE F-9        37                        7.0
FILE F-9        38
FILE F-9        38                        7.0       15572.
ENDFILE F-9
FILE G                                                                          1
ENDFILE
FILE H      1                                                                29.3
FILE H      2                                                                48.3
FILE H      3                                                                338.0
ENDFILE H
FILE I          01    22.
FILE I          02    22.
FILE I          03    22.       56.
FILE I          04    22.
FILE I          05    23.       40.
FILE I          06     23.
FILE I          07    23.
FILE I          08    23.
FILE I          09    23.
FILE I          10    23.       2.
FILE I          11    20.
FILE I          12    20.
FILE I          13     19.
FILE I          14    19.
FILE I          15    19.
FILE I          16    19.
FILE I          17    19.
FILE I          18    19.
FILE I          19    19.
FILE I          20    19.
FILE I          21    26.
FILE I          22    26.       6.
FILE I          23    28.8
FILE I          24    29.
FILE I          25    29.       10.
FILE I          26    31.5      5.
FILE I          27    30.       4.
FILE I          28    30.       11.
FILE I          29    30.
FILE I          30    30.2      6.
FILE I          31    30.2
FILE I          32    25.
FILE I          33    21.5
FILE I          34    22.
FILE I          35    23.
FILE I          36    23.
FILE I          37    23.
FILE I          38    22.5
ENDFILE I
FILE J     .15  4.0            .30  6.6  .27  .10
ENDFILE J
FILE K-1        01      .15                .25                  3.
FILE K-1        02      .15                .25                  3.
FILE K-1        03      .15                .25                  3.
FILE K-1        04      .15                .25                  3.
FILE K-1        05      .15                .25                  3.
FILE K-1        06      .15                .25                  3.
FILE K-1        07      .15                .25                  3.
FILE K-1        08      .15                .25                  3.
FILE K-1        09      .15                .25                  3.
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FILE K-1        11      .15                .25                  3.
FILE K-1        12      .15                .25                  3.
FILE K-1        13      .15                .25                  3.
FILE K-1        14      .15                .25                  3.
FILE K-1        15      .15                .25                  3.
FILE K-1        16      .15                .25                  3.
FILE K-1        17      .15                .25                  3.
FILE K-1        18      .15                .25                  3.
FILE K-1        19      .15                .25                  3.
FILE K-1        20      .15                .25                  3.
FILE K-1        21      .15                .25                  3.
FILE K-1        22      .15                .25                  3.
FILE K-1        23      .15                .25                  3.
FILE K-1        24      .15                .25                  3.
FILE K-1        25      .15                .25                  3.
FILE K-1        26      .15                .25                  3.
FILE K-1        27      .15                .25                  3.
FILE K-1        28      .15                .25                  3.
FILE K-1        29      .15                .25                  3.
FILE K-1        30      .15                .25                  3.
FILE K-1        31      .15                .25                  3.
FILE K-1        32      .15                .25                  3.
FILE K-1        33      .15                .25                  3.
FILE K-1        34      .15                .25                  3.
FILE K-1        35      .15                .25                  3.
FILE K-1        36      .15                .25                  3.
FILE K-1        37      .15                .25                  3.
FILE K-1        38      .15                .25                  3.
ENDFILE K-1
FILE K-2        01     .20                 .3                   1.
FILE K-2        02     .20                 .3                   1.
FILE K-2        03     .20                 .3                   1.
FILE K-2        04     .20                 .3                   1.
FILE K-2        05     .20                 .3                   1.
FILE K-2        06     .20                 .3                   1.
FILE K-2        07     .20                 .3                   1.
FILE K-2        08     .20                 .3                   1.
FILE K-2        09     .20                 .3                   1.
FILE K-2        10     .20                 .3                   1.
FILE K-2        11     .20                 .3                   1.
FILE K-2        12     .20                 .3                   1.
FILE K-2        13     .20                 .3                   1.
FILE K-2        14     .20                 .3                   1.
FILE K-2        15     .20                 .3                   1.
FILE K-2        16     .20                 .3                   1.
FILE K-2        17     .20                 .3                   1.
FILE K-2        18     .20                 .3                   1.
FILE K-2        19     .20                 .3                   1.
FILE K-2        20     .20                 .3                   1.
FILE K-2        21     .20                 .3                   1.
FILE K-2        22     .20                 .3                   1.
FILE K-2        23    .20              .3               1.
FILE K-2        24    .20              .3               1.
FILE K-2        25    .20              .3               1.
FILE K-2        26    .20              .3               1.
FILE K-2        27    .20              .3               1.
FILE K-2        28    .20              .3               1.
FILE K-2        29    .20              .3               1.
FILE K-2        30    .20              .3               1.
FILE K-2        31    .20              .3               1.
FILE K-7        32    .20              .3               1.
FILE K-2        33    .20              .3               1.
FILE K-2        34    .20              .3               1.
FILE K-2        35    .20              .3               1.
FILE K-2        36    .20              .3               1.
FILE K-2        37    .20              .3               1.
FILE K-2        39    .20              .3               1.
ENDFILE K-2
FILE K-3        01    2.0              .1
FILE K-3        02    2.0              .1
FILE K-3        03    2.0              .1
FILE K-3        U4    2.0              .1
FILE K-3        05    2.0              .1
FILE K-3        06    2.0              .1
FILE K-3        07    2.0              .1
FILE K-3        08    2.0              .1
FILE K-3        09    2.0              .1
FILE K-3        10    2.0              .1
FILE K-3        11    2.0              .1
FILE K-3        12    2.0              .1
FILE K-3        13    2.0              .1
FILE K-3        14    2.0              .1
FILE K-3        15    2.0              .1
FILE K-3        16    2.0              .1
FILE K-3        17    2.0              .1
FILE K-3        18    2.0              .1
FILE K-3        19    2.0              .1
FILE K-3        20    2.0              .1
FILE K-3        21    2.0              .1
FILE K-3        22    2.0              .1
FILE K-3        23    2.0              .1
FILE K-3        24    2.0              .1
FILE K-3        25    2.0              .1
FILE K-3        26    2.0              .1
FILE K-3        27    2.0              .1
FILE K-3        28    2.0              .1
FILE K-3        29    2.0              .1
FILE K-3        30    2.0              .1
FILE K-3        31    2.0              .1
FILE K-3        32    2.0              .1
FILE K-3        33    2.0              .1
FILE K-3        34    2.0              .1
FILE K-3        J5    2.0              .1
FILE K-3        36    2.0              .1
FILE K-3        37    2.0              .1
FILE K-3        38    2.0              .1
ENDFILE K-3
```

PRELIMINARY DESIGN DATA DECK

```
CONTROL T 001020011221011120    1.    60  1.   5.   2.   .5  .25     T
USGS     01  03091500 05 0102030405
USGS     02  03094000 07 0607080910
USGS     03  03098000 25 212223242526
USGS     04  03099500 29 2728293031
USGS     05  03103500 13 1314151617181920
USGS     06  03105500 33 323334
USGS     07  03107500 36 35363738
USGS     08  03095500 11 1112
END
```

"RIBAM SDD"

```
CHAR0501        1500.
CHAR0502        1500.
CHAR0503        1500.
CHAR0504        1500.
CHAR0505        1500.
CHAR0506        1500.
CHAR0507        1500.
CHAR0508        1500.
CHAR0509        1500.
CHAR0510        1500.
CHAR0511        1500.
CHAR0512        1500.
CHAR0513         500.
CHAR0514         500.
CHAR0515         500.
CHAR0516         500.
CHAR0517         500.
CHAR0518         500.
CHAR0519         500.
CHAR0520         500.
CHAR0521        1500.
CHAR0522        1500.
CHAR0523        1500.
CHAR0524        1500.
CHAR0525        1500.
CHAR0526        1500.
CHAR0527        1500.
CHAR0528        1500.
CHAR0529        1500.
CHAR0530         500.
CHAR0531         500.
CHAR0532         500.
CHAR0533         500.
CHAR0534         500.
CHAR0535         500.
CHAR0536         500.
CHAR0537         500.
CHAR0538         500.
END
CHAR1001         .005
CHAR1002         .005
CHAR1003         .005
CHAR1004         .005
CHAR1005         .005
CHAR1006         .005
CHAR1007         .005
CHAR1008         .005
CHAR1009         .005
CHAR1010         .005
CHAR1011         .005
CHAR1012         .005
```

```
CHAR1013        .0
CHAR1014        .0
CHAR1015        .0
CHAR1016        .0
CHAR1017        .0
CHAR1018        .0
CHAR1019        .0
CHAR1020        .0
CHAR1021        .005
CHAR1022        .005
CHAR1023        .005
CHAR1024        .005
CHAR1025        .005
CHAR1026        .005
CHAR1027        .005
CHAR1028        .005
CHAR1029        .005
CHAR1030        .0
CHAR1031        .0
CHAR1032       0.00
CHAR1033       0.0
CHAR1034       0.0
CHAR1035       0.00
CHAR1036       0.0
CHAR1037       0.0
CHAR1038       0.0
END
CHAR1101         0.1
CHAR1102         0.1
CHAR1103         0.1
CHAR1104         0.1
CHAR1105         0.1
CHAR1106         0.1
CHAR1107         0.1
CHAR1108         0.1
CHAR1109         0.1
CHAR1110         0.1
CHAR1111         0.1
CHAR1112         0.1
CHAR1113       0.005
CHAR1114       0.005
CHAR1115       0.005
CHAR1116       0.005
CHAR1117       0.005
CHAR1118       0.005
CHAR1119       0.005
CHAR1120       0.005
CHAR1121         0.1
CHAR1122         0.1
CHAR1123         0.1
CHAR1124         0.1
CHAR1125         0.1
CHAR1126         0.1
CHAR1127         0.1
CHAR1128         0.1
CHAR1129         0.1
CHAR1130       0.005
CHAR1131       0.005
CHAR1132       0.005
CHAR1133       0.005
CHAR1134       0.005
CHAR1135       0.005
CHAR1136       0.005
CHAR1137       0.005
CHAR1138       0.005
END
```

```
CHAR1701          5.0
CHAR1702          5.0
CHAR1703          5.0
CHAR1704          5.0
CHAR1705          5.0
CHAR1706          5.0
CHAR1707          5.0
CHAR1708          5.0
CHAR1709          5.0
CHAR1710          5.0
CHAR1711          5.0
CHAR1712          5.0
CHAR1713          5.0
CHAR1714          5.0
CHAR1715          5.0
CHAR1716          5.0
CHAR1717          5.0
CHAR1718          5.0
CHAR1719          5.0
CHAR1720          5.0
CHAR1721          5.0
CHAR1722          5.0
CHAR1723          5.0
CHAR1724          5.0
CHAR1725          5.0
CHAR1726          5.0
CHAR1727          5.0
CHAR1728          5.0
CHAR1729          5.0
CHAR1730          5.0
CHAR1731          5.0
CHAR1732          5.0
CHAR1733          5.0
CHAR1734          5.0
CHAR1735          5.0
CHAR1736          5.0
CHAR1737          5.0
CHAR1738          5.0
END
```

CANDIDATE 1.0 DATA DECK

```
CONTROL F 001020011221011120     1.     60  1.    5.    2.    .5  .25     T
USGS     01   03091500 05 0102030405
USGS     02   03094000 07 0607080910
USGS     03   03098000 25 212223242526
USGS     04   03099500 29 2728293031
USGS     05   03103500 13 1314151617181920
USGS     06   03105500 33 323334
USGS     07   03107500 36 35363738
USGS     08   03095500 11 1112
END
```

"RIBAM SDD"

```
CHAR0501         1500.
CHAR0502         1500.
CHAR0503         1500.
CHAR0504         1500.
CHAR0505         1500.
CHAR0506         1500.
CHAR0507         1500.
CHAR0508         1500.
CHAR0509         1500.
CHAR0510         1500.
CHAR0511         1500.
```

```
CHAR0512      1500.
CHAR0513       500.
CHAR0514       500.
CHAR0515       500.
CHAR0516       500.
CHAR0517       500.
CHAR0518       500.
CHAR0519       500.
CHAR0520       500.
CHAR0521      1500.
CHAR0522      1500.
CHAR0523      1500.
CHAR0524      1500.
CHAR0525      1500.
CHAR0526      1500.
CHAR0527      1500.
CHAR0528      1500.
CHAR0529      1500.
CHAR0530TT     500.     7.0      11.0      15.0      15.0      365.      0.
CHAR0531       500.
CHAR0532       500.
CHAR0533       500.
CHAR0534       500.
CHAR0535       500.
CHAR0536       500.
CHAR0537       500.
CHAR0538       500.
END
CHAR1001       .005
CHAR1002       .005
CHAR1003       .005
CHAR1004       .005
CHAR1005       .005
CHAR1006       .005
CHAR1007       .005
CHAR1008       .005
CHAR1009       .005
CHAR1010       .005
CHAR1011       .005
CHAR1012       .005
CHAR1013       .0
CHAR1014       .0
CHAR1015       .0
CHAR1016       .0
CHAR1017       .0
CHAR1018       .0
CHAR1019       .0
CHAR1020       .0
CHAR1021TT     .005     7.0      30.6      0.05      0.10      365.      0.
CHAR1022       .005
CHAR1023       .005
CHAR1024       .005
CHAR1025       .005
CHAR1026       .005
CHAR1027       .005
CHAR1028       .005
CHAR1029       .005
CHAR1030       .0
CHAR1031       .0
CHAR1032       0.00
CHAR1033       0.0
CHAR1034       0.0
CHAR1035       0.00
CHAR1036       0.0
CHAR1037       0.0
CHAR1038       0.0
END
```

```
CHAR1101         0.1
CHAR1102         0.1
CHAR1103         0.1
CHAR1104         0.1
CHAR1105         0.1
CHAR1106         0.1
CHAR1107         0.1
CHAR1108         0.1
CHAR1109TT      0.1      14.       37.0      .001      .002       365.      0.
CHAR1110         0.1
CHAR1111         0.1
CHAR1112         0.1
CHAR1113       0.005
CHAR1114       0.005
CHAR1115       0.005
CHAR1116       0.005
CHAR1117       0.005
CHAR1118       0.005
CHAR1119       0.005
CHAR1120       0.005
CHAR1121TT      0.1       7.0      30.6      0.001     0.002      365.      0.
CHAR1122         0.1
CHAR1123         0.1
CHAR1124         0.1
CHAR1125         0.1
CHAR1126         0.1
CHAR1127         0.1
CHAR1128         0.1
CHAR1129         0.1
CHAR1130TT     0.005      7.       11.0     0.001     0.002      365.      0.
CHAR1131       0.005
CHAR1132       0.005
CHAR1133       0.005
CHAR1134       0.005
CHAR1135       0.005
CHAR1136       0.005
CHAR1137       0.005
CHAR1138     0.005
END
CHAR1701         5.0
CHAR1702TT     5.0      45.       82.5      0.02      0.10       365.     0.
CHAR1703         5.0
CHAR1704         5.0
CHAR1705         5.0
CHAR1706         5.0
CHAR1707         5.0
CHAR1708         5.0
CHAR1709         5.0
CHAR1710     5.0
CHAR1711         5.0
CHAR1712         5.0
CHAR1713         5.0
CHAR1714         5.0
CHAR1715         5.0
CHAR1716         5.0
CHAR1717         5.0
CHAR1718TT     5.0      7.        36.8      0.02      0.10      365.      0.
CHAR1719         5.0
CHAR1720         5.0
CHAR1721TT     5.0      7.        30.6     0.02       0.10      365.     0.
CHAR1722         5.0
CHAR1723         5.0
CHAR1724         5.0
CHAR1725         5.0
CHAR1726         5.0
CHAR1727         5.0
```

```
CHAR1728          5.0
CHAR1729          5.0
CHAR1730          5.0
CHAR1731          5.0
CHAR1732          5.0
CHAR1733          5.0
CHAR1734          5.0
CHAR1735          5.0
CHAR1736TT       5.0        7.0       4.0        0.02        0.10        365.        0.
CHAR1737          5.0
CHAR1738          5.0
END
MTTF     01        0.2       0.01        2.0        1.0      365.       365.
MTTF     02       0.01       0.01        2.0       0.01      365.       365.
MTTF     03       0.01       0.01        2.0       0.01      365.       365.
MTTF     04        0.2       0.01        4.0        2.0      365.       365.
MTTF     05       0.02       0.02        4.0        0.1       52.        52.
MTTF     06        0.2       0.01        2.0        1.0      365.       365.
MTTF     07       0.01       0.01        2.0       0.01      365.       365.
MTTF     08       0.01       0.01        2.0       0.01      365.       365.
MTTF     09        0.2       0.01        4.0        2.0      365.       365.
MTTF     10        0.2       0.01        2.0        1.0      365.       365.
MTTF     11       0.01       0.01        2.0       0.01      365.       365.
MTTF     12        0.2       0.01        4.0        2.0      365.       365.
MTTF     13        0.2       0.01        4.0        2.0      365.       365.
MTTF     14       0.02       0.02        4.0        0.1       52.        52.
MTTF     15        0.2       0.01        2.0        1.0      365.       365.
MTTF     16       0.01       0.01        2.0        .01      365.       365.
MTTF     17        0.2       0.01        4.0        2.0      365.       365.
MTTF     18        0.2       0.01        4.0        2.0      365.       365.
MTTF     19        0.2        0.1        4.0        1.0      122.       122.
END
SURV     30    05     1     1S02S03
SURV     30    05     2     1M10M13P03
SURV     30    05     3     2M15M18P02
END
AVAIL    30    05     1     1S02S03
AVAIL    30    05     2     1M10M13P03
AVAIL    30    05     3     2M15M18P02
END
SURV     21    10     1     1S02S03
SURV     21    10     2     1M01M02P03
SURV     21    10     3     2M06M07P02
END
AVAIL    21    10     1     1S02S03
AVAIL    21    10     2     1M01M02P03
AVAIL    21    10     3     2M06M07P02
END
SURV     09    11     1     1M05S02S03
SURV     09    11     2     1M01M03P03
SURV     09    11     3     2M06M08P02
SURV     21    11     1     1S02S03M05
SURV     21    11     2     1M01M03P03
SURV     21    11     3     2M06M08P02
SURV     30    11     1     1M14S02S03
SURV     30    11     2     1M10M11P03
SURV     30    11     3     2M15M16P02
END
AVAIL    09    11     1     1M05S02S03
AVAIL    09    11     2     1M01M03P03
AVAIL    09    11     3     2M06M08P02
AVAIL    21    11     1     1S02S03M05
AVAIL    21    11     2     1M01M03P03
AVAIL    21    11     3     2M06M08P02
AVAIL    30    11     1     1M14S02S03
AVAIL    30    11     2     1M10M11P03
AVAIL    30    11    3    2M15M16P02
END
SURV     02    17    1    1S02S03M19
SURV     02    17    2    1M01M04P03
SURV     02    17    3    2M06M09P02
SURV     18    17    1    1S02S03
SURV     18    17    2    1M10M12P03
SURV     18    17    3    2M15M17P02
SURV     21    17    1    1S02S03
SURV     21    17    2    1M01M04P03
SURV     21    17    3    2M06M09P02
SURV     36    17    1    1S02S03
SURV     36    17    2    1M10M12P03
SURV     36    17    3    2M15M17P02
END
AVAIL    02    17    1    1S02S03M19
AVAIL    02    17    2    1M01M04P03
AVAIL    02    17    3    2M06M09P02
AVAIL    18    17    1    1S02S03
AVAIL    18    17    2    1M10M12P03
AVAIL    18    17    3    2M15M17P02
AVAIL    21    17    1    1S02S03
AVAIL    21    17    2    1M01M04P03
AVAIL    21    17    3    2M06M09P02
AVAIL    36    17    1    1S02S03
AVAIL    36    17    2    1M10M12P03
AVAIL    36    17    3    2M15M17P02
END
COSTG     1    40000.        0.        0.        0.    0
COSTG     2    10000.     5000.        0.        0.    1
COSTG     3    20000.     4500.     1000.    20000.    2
COSTG     4     5000.     2500.      500.     4500.    2
COSTG     5    10000.     5000.        0.        0.    1
COSTG     6    20000.     4500.     1000.    20000.    5
COSTG     7     5000.     1500.      250.     4500.    5
COSTG     8     5000.     1500.      250.     4500.    5
COSTM     1     3000.     5000.      400.     2000.    4
COSTM     2      400.      500.        0.        0.    4
COSTM     3      400.      500.        0.        0.    4
COSTM     4      600.       10.      100.      300.    4
COSTM     5     1500.       50.        0.     1500.    3
COSTM     6     3000. 1000.      400.      2000.       4
COSTM     7      400. 50.                  0.        0.    4
COSTM     8      400.  50.                 0.        0.    4
COSTM     9      600.       10.      100.      300.    4
COSTM    10     3000.     5000.      400.     2000.    7
COSTM    11      400.      500.        0.        0.    7
COSTM    12      600.       10.      100.      300.    7
COSTM    13      300.       10.       50.      150.    7
COSTM    14     1500.       50.        0.     1500.    6
COSTM    15     3000.  1000.           400.     2000.    8
COSTM    16      400.  50.              0.        0.    8
COSTM    17      600.       10.      100.      300.    8
COSTM    18      300.       10.       50.      150.    8
COSTM    19     1500.      100.      100.     1000.    4
END
#
```

CANDIDATE 1.0 RESULTS

```
DESIGN TYPE = F SYSTEM DUR. =    1.00 NO. OF MONTHS =    60 FLOW SCALING FACTORS =   1.0  5.0  2.0   .5   .3

 STA. NO.      STA. I.D.       SEG. NO.     SEG. ASSOCIATION


     1           3091500           5        1 2 3 4 5-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
     2           3094000           7        6 7 8 910-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
     3           3098000          25       212223242526-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
     4           3099500          29       2728293031-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
     5           3103500          13       1314151617181920-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
     6           3105500          33       323334-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
     7           3107500          36       35363738-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
     8           3095500          11       1112-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

 PARAMETER NUMBER =    5
 REACH NO. IMPL.   MN. PLCY.   CT     DELTA   IMPL. LOC.   EPSI     SEPSI    TUP      TDOWN


     1     F          F     1500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
     2     F          F     1500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
     3     F          F     1500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
     4     F          F     1500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
     5     F          F     1500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
     6     F          F     1500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
     7     F          F     1500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
     8     F          F     1500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
     9     F          F     1500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
    10     F          F     1500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
    11     F          F     1500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
    12     F          F     1500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
    13     F          F      500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
    14     F          F      500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
    15     F          F      500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
    16     F          F      500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
    17     F          F      500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
    18     F          F      500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
    19     F          F      500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
    20     F          F      500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
    21     F          F     1500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
    22     F          F     1500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
    23     F          F     1500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
    24     F          F     1500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
    25     F          F     1500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
    26     F          F     1500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
    27     F          F     1500.000  -0.00    -0.00     -0.000   -0.000   -0.00   -0.00
    28     F          F    1500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    29     F          F    1500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    30     T          T     500.000    7.00     11.00      15.000   15.000  365.00    0.00
    31     F          F     500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    32     F          F     500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    33     F          F     500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    34     F          F     500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    35     F          F     500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    36     F          F     500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    37     F          F     500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    38     F          F     500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00

PARAMETER NUMBER =  10
REACH NO. IMPL.   MN. PLCY.   CT     DELTA   IMPL. LOC.    EPSI     SEPSI     TUP     TDOWN


     1     F          F         .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     2     F          F         .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     3     F          F         .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     4     F          F         .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     5     F          F         .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     6     F          F         .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     7     F          F         .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     8     F          F         .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     9     F          F         .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    10     F          F         .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    11     F          F         .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    12     F          F         .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    13     F          F        0.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    14     F          F        0.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    15     F          F        0.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    16     F          F        0.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    17     F          F        0.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    18     F          F        0.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    19     F          F        0.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    20     F          F        0.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    21     T          T         .005    7.00     30.60        .050     .100  365.00    0.00
    22     F          F         .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    23     F          F         .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    24     F          F         .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    25     F          F         .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    26     F          F         .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    27     F          F         .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    28     F          F         .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    29     F          F         .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    30     F          F        0.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
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   31      F          F        0.000  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   32      F          F        0.000  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   33      F          F        0.000  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   34      F          F        0.000  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   35      F          F        0.000  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   36      F          F        0.000  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   37      F          F        0.000  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   38      F          F        0.000  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
PARAMETER NUMBER =  11
REACH NO. IMPL.    MN. PLCY.   CT    DELTA   IMPL. LOC.   EPSI    SEPSI    TUP     TDOWN


    1      F          F         .100  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
    2      F          F         .100  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
    3      F          F         .100  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
    4      F          F         .100  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
    5      F          F         .100  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
    6      F          F         .100  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
    7      F          F         .100  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
    8      F          F         .100  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
    9      T          T         .100  14.00     37.00       .001    .002  365.00    0.00
   10      F          F         .100  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   11      F          F         .100  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   12      F          F         .100  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   13      F          F         .005  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   14      F          F         .005  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   15      F          F         .005  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   16      F          F         .005  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   17      F          F         .005  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   18      F          F         .005  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   19      F          F         .005  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   20      F          F         .005  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   21      T          T         .100   7.00     30.60       .001    .002  365.00    0.00
   22      F          F         .100  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   23      F          F         .100  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   24      F          F         .100  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   25      F          F         .100  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   26      F          F         .100  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   27      F          F         .100  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   28      F          F         .100  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   29      F          F         .100  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   30      T          T         .005   7.00     11.00       .001    .002  365.00    0.00
   31      F          F         .005  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   32      F          F         .005  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   33      F          F         .005  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   34      F          F         .005  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
   35      F          F         .005  -0.00     -0.00     -0.000  -0.000   -0.00   -0.00
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      36      F         F        .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      37      F         F        .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      38      F         F        .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00

PARAMETER NUMBER =  17

REACH NO. IMPL.     MN. PLCY.   CT      DELTA   IMPL. LOC.    EPSI     SEPSI    TUP     TDOWN


       1      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
       2      T         T       5.000   45.00     82.50        .020     .100  365.00    0.00
       3      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
       4      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
       5      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
       6      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
       7      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
       8      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
       9      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      10      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      11      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      12      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      13      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      14      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      15      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      16      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      17      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      18      T         T       5.000    7.00     36.80        .020     .100  365.00    0.00
      19      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      20      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      21      T         T       5.000    7.00     30.60        .020     .100  365.00    0.00
      22      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      23      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      24      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      25      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      26      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      27      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      28      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      29      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      30      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      31      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      32      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      33      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      34      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      35      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      36      T         T       5.000    7.00      4.00        .020     .100  365.00    0.00
      37      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      38      F         F       5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
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                    STATE 1 = OPERATING, STATE 2 = STAND-BY
MEANS NO..   MTTFS-1    MTTFS-2    MTTFA-1    MTTFA-2    MTTRA-1    MTTRA-2

    1          .20        .01        2.00       1.00      365.00     365.00
    2          .01        .01        2.00        .01      365.00     365.00
    3          .01        .01        2.00        .01      365.00     365.00
    4          .20        .01        4.00       2.00      365.00     365.00
    5          .02        .02        4.00        .10       52.00      52.00
    6          .20        .01        2.00       1.00      365.00     365.00
    7          .01        .01        2.00        .01      365.00     365.00
    8          .01        .01        2.00        .01      365.00     365.00
    9          .20        .01        4.00       2.00      365.00     365.00
   10          .20        .01        2.00       1.00      365.00     365.00
   11          .01        .01        2.00        .01      365.00     365.00
   12          .20        .01        4.00       2.00      365.00     365.00
   13          .20        .01        4.00       2.00      365.00     365.00
   14          .02        .02        4.00        .10       52.00      52.00
   15          .20        .01        2.00       1.00      365.00     365.00
   16          .01        .01        2.00        .01      365.00     365.00
   17          .20        .01        4.00       2.00      365.00     365.00
   18          .20        .01        4.00       2.00      365.00     365.00
   19          .20        .10        4.00       1.00      122.00     122.00


        PARAMETER NUMBER =  5 ELEMENT DESIGN FOR SURVIVABILITY

        REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

            30         1            1        S 25 3 -0 -0 -0 -0 -0 -0 -0 -0
            30         2            1        M10M13P 3 -0 -0 -0 -0 -0 -0 -0
            30         3            2        M15M18P 2 -0 -0 -0 -0 -0 -0 -0

        PARAMETER NUMBER =   5 ELEMENT DESIGN FOR AVAILABILITY

        REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

            30         1            1        S 25 3 -0 -0 -0 -0 -0 -0 -0 -0
            30         2            1        M10M13P 3 -0 -0 -0 -0 -0 -0 -0
            30         3            2        M15M18P 2 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                 LUDATF      2
*** I M S L(UERTST) ***  WARNING                 LEQT1F      2

PARAMETER NUMBER =   5

REACH NO. =  30 CAP =   3.58132E-03 SURV =   9.35785E-01 AVAIL =   9.99801E-01 ELEMENT EFF. =   3.35068E-03



        PARAMETER NUMBER = 10 ELEMENT DESIGN FOR SURVIVABILITY

        REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

            21         1            1        S 25 3 -0 -0 -0 -0 -0 -0 -0 -0
            21         2            1        M 1M 2P 3 -0 -0 -0 -0 -0 -0 -0
            21         3            2        M 6M 7P 2 -0 -0 -0 -0 -0 -0 -0
        PARAMETER NUMBER =  10 ELEMENT DESIGN FOR AVAILABILITY

        REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

            21         1            1        S 25 3 -0 -0 -0 -0 -0 -0 -0 -0
            21         2            1        M 1M 2P 3 -0 -0 -0 -0 -0 -0 -0
            21         3            2        M 6M 7P 2 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                 LUDATF      2
*** I M S L(UERTST) ***  WARNING                 LEQT1F      2

PARAMETER NUMBER =  10

REACH NO. =  21 CAP =   1.73213E-02 SURV =   9.79116E-01 AVAIL =   9.99925E-01 ELEMENT EFF. =   1.69583E-02
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PARAMETER NUMBER = 11 ELEMENT DESIGN FOR SURVIVABILITY

REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

     9         1            1        M 5S 2S 3 -0 -0 -0 -0 -0 -0 -0
     9         2            1        M 1M 3P 3 -0 -0 -0 -0 -0 -0 -0
     9         3            2        M 6M 8P 2 -0 -0 -0 -0 -0 -0 -0
    21         1            1        S 2S 3M 5 -0 -0 -0 -0 -0 -0 -0
    21         2            1        M 1M 3P 3 -0 -0 -0 -0 -0 -0 -0
    21         3            2        M 6M 8P 2 -0 -0 -0 -0 -0 -0 -0
    30         1            1        M14S 2S 3 -0 -0 -0 -0 -0 -0 -0
    30         2            1        M10M11P 3 -0 -0 -0 -0 -0 -0 -0
    30         3            2        M15M16P 2 -0 -0 -0 -0 -0 -0 -0
PARAMETER NUMBER =  11 ELEMENT DESIGN FOR AVAILABILITY

REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

           9         1            1        M 5S 2S 3 -0 -0 -0 -0 -0 -0 -0
           9         2            1        M 1M 3P 3 -0 -0 -0 -0 -0 -0 -0
           9         3            2        M 6M 8P 2 -0 -0 -0 -0 -0 -0 -0
          21         1            1        S 2S 3M 5 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                LUDATF      2
*** I M S L(UERTST) ***  WARNING                LEQT1F      2
          21         2            1        M 1M 3P 3 -0 -0 -0 -0 -0 -0 -0
          21         3            2        M 6M 8P 2 -0 -0 -0 -0 -0 -0 -0
          30         1            1        M14S 2S 3 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                LUDATF      2
*** I M S L(UERTST) ***  WARNING                LEQT1F      2
          30         2            1        M10M11P 3 -0 -0 -0 -0 -0 -0 -0
          30         3            2        M15M16P 2 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                LUDATF      2
*** I M S L(UERTST) ***  WARNING                LEQT1F      2

PARAMETER NUMBER =  11

REACH NO. =   9 CAP =   8.83016E-03 SURV =   9.59728E-01 AVAIL =   9.28502E-01 ELEMENT EFF. =   7.86864E-03

REACH NO. =  21 CAP =   7.42334E-04 SURV =   9.59728E-01 AVAIL =   9.28502E-01 ELEMENT EFF. =   6.61501E-04

REACH NO. =  30 CAP =   5.65705E-03 SURV =   9.59728E-01 AVAIL =   9.28502E-01 ELEMENT EFF. =   5.04105E-03
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PARAMETER NUMBER = 17 ELEMENT DESIGN FOR SURVIVABILITY

REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

     2         1            1        S 2S 3M19 -0 -0 -0 -0 -0 -0 -0
     2         2            1        M 1M 4P 3 -0 -0 -0 -0 -0 -0 -0
     2         3            2        M 6M 9P 2 -0 -0 -0 -0 -0 -0 -0
    10         1            1        S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
    10         2            1        M10M12P 3 -0 -0 -0 -0 -0 -0 -0
    10         3            2        M15M17P 2 -0 -0 -0 -0 -0 -0 -0
    21         1            1        S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
    21         2            1        M 1M 4P 3 -0 -0 -0 -0 -0 -0 -0
    21         3            2        M 6M 9P 2 -0 -0 -0 -0 -0 -0 -0
    36         1            1        S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
    36         2            1        M10M12P 3 -0 -0 -0 -0 -0 -0 -0
    36         3            2        M15M17P 2 -0 -0 -0 -0 -0 -0 -0

PARAMETER NUMBER =  17 ELEMENT DESIGN FOR AVAILABILITY

REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

           2         1            1        S 2S 3M19 -0 -0 -0 -0 -0 -0 -0
           2         2            1        M 1M 4P 3 -0 -0 -0 -0 -0 -0 -0
           2         3            2        M 6M 9P 2 -0 -0 -0 -0 -0 -0 -0
          10         1            1        S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                LUDATF      2
*** I M S L(UERTST) ***  WARNING                LEQT1F      2
          10         2            1        M10M12P 3 -0 -0 -0 -0 -0 -0 -0
          10         3            2        M15M17P 2 -0 -0 -0 -0 -0 -0 -0
          21         1            1        S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                LUDATF      2
*** I M S L(UERTST) ***  WARNING                LEQT1F      2
          21         2            1        M 1M 4P 3 -0 -0 -0 -0 -0 -0 -0
          21         3            2        M 6M 9P 2 -0 -0 -0 -0 -0 -0 -0
          36         1            1        S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
```

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*** I M S L(UERTST) ***  WARNING              LUDATF     2
*** I M S L(UERTST) ***  WARNING              LEQT1F     2
          36        2           1       M10M12P 3 -0 -0 -0 -0 -0 -0 -0
          36        3           2       M15M17P 2 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING              LUDATF     2
*** I M S L(UERTST) ***  WARNING              LEQT1F     2

PARAMETER NUMBER =  17

REACH NO. =   2 CAP =   1.14610E-03 SURV =   7.66156E-01 AVAIL =   9.68061E-01 ELEMENT EFF. =   8.50045E-04

REACH NO. =  18 CAP =   1.71128E-02 SURV =   9.35785E-01 AVAIL =   9.99801E-01 ELEMENT EFF. =   1.60107E-02

REACH NO. =  21 CAP =   1.70510E-02 SURV =   9.35785E-01 AVAIL =   9.99801E-01 ELEMENT EFF. =   1.59529E-02

REACH NO. =  36 CAP =   1.74748E-02 SURV =   9.35785E-01 AVAIL =   9.99801E-01 ELEMENT EFF. =   1.63494E-02


 SYSTEM EFFECTIVENESS =   1.51062E-01

TOTAL COST =   1.53510E+05

COST/EFF. =   1.01620E+06
```

CANDIDATE 2.0 DATA DECK

```
CONTROL F 001020011221011120     1.    60  1.   5.   2.   .5  .25     T
USGS     01  03091500 05 0102030405
USGS     02  03094000 07 0607080910
USGS     03  03098000 25 212223242526
USGS     04  03099500 29 2728293031
USGS     05  03103500 13 1314151617181920
USGS     06  03105500 33 323334
USGS     07  03107500 36 35363738
USGS     08  03095500 11 1112
END
```

"RIBAM SDD"

```
CHAR0501        1500.
CHAR0502        1500.
CHAR0503        1500.
CHAR0504        1500.
CHAR0505        1500.
CHAR0506        1500.
CHAR0507        1500.
CHAR0508        1500.
CHAR0509        1500.
CHAR0510        1500.
CHAR0511        1500.
CHAR0512        1500.
CHAR0513         500.
CHAR0514         500.
CHAR0515         500.
CHAR0516         500.
CHAR0517         500.
CHAR0518         500.
CHAR0519         500.
CHAR0520         500.
CHAR0521        1500.
CHAR0522        1500.
CHAR0523        1500.
CHAR0524        1500.
CHAR0525        1500.
CHAR0526        1500.
```

```
CHAR0527       1500.
CHAR0528       1500.
CHAR0529       1500.
CHAR0530TT   500.         0.0417      12.5       15.0       60.0       6.75     0.25
CHAR0531        500.
CHAR0532        500.
CHAR0533        500.
CHAR0534        500.
CHAR0535        500.
CHAR0536        500.
CHAR0537        500.
CHAR0538        500.
END
CHAR1001        .005
CHAR1002        .005
CHAR1003        .005
CHAR1004        .005
CHAR1005        .005
CHAR1006        .005
CHAR1007        .005
CHAR1008        .005
CHAR1009        .005
CHAR1010        .005
CHAR1011        .005
CHAR1012        .005
CHAR1013        .0
CHAR1014        .0
CHAR1015        .0
CHAR1016        .0
CHAR1017        .0
CHAR1018        .0
CHAR1019        .0
CHAR1020        .0
CHAR1021TT   .005         0.0417      31.0       0.02       0.15       6.75     0.25
CHAR1022        .005
CHAR1023        .005
CHAR1024        .005
CHAR1025        .005
CHAR1026        .005
CHAR1027        .005
CHAR1028        .005
CHAR1029        .005
CHAR1030        .0
CHAR1031        .0
CHAR1032      0.00
CHAR1033      0.0
CHAR1034      0.0
CHAR1035      0.00
CHAR1036      0.0
CHAR1037      0.0
CHAR1038      0.0
END
CHAR1101        0.1
CHAR1102        0.1
CHAR1103        0.1
CHAR1104        0.1
CHAR1105        0.1
CHAR1106        0.1
CHAR1107        0.1
CHAR1108        0.1
CHAR1109TT   0.1          0.0417      37.00      .001       .005       6.75     0.25
CHAR1110        0.1
CHAR1111        0.1
CHAR1112        0.1
CHAR1113      0.005
CHAR1114      0.005
```

```
CHAR1115        0.005
CHAR1116        0.005
CHAR1117        0.005
CHAR1118        0.005
CHAR1119        0.005
CHAR1120        0.005
CHAR1121TT   0.1            0.0417       31.0       .001       .005       6.75     0.25
CHAR1122          0.1
CHAR1123          0.1
CHAR1124          0.1
CHAR1125          0.1
CHAR1126          0.1
CHAR1127          0.1
CHAR1128          0.1
CHAR1129          0.1
CHAR1130TT  0.005           0.0417       12.5       .001       .005       6.75     0.25
CHAR1131        0.005
CHAR1132        0.005
CHAR1133        0.005
CHAR1134        0.005
CHAR1135        0.005
CHAR1136        0.005
CHAR1137        0.005
CHAR1138      0.005
END
CHAR1701          5.0
CHAR1702TT   5.0            0.0417       82.5       0.05       0.15       6.75     0.25
CHAR1703          5.0
CHAR1704          5.0
CHAR1705          5.0
CHAR1706          5.0
CHAR1707          5.0
CHAR1708          5.0
CHAR1709          5.0
CHAR1710          5.0
CHAR1711          5.0
CHAR1712          5.0
CHAR1713          5.0
CHAR1714          5.0
CHAR1715          5.0
CHAR1716          5.0
CHAR1717          5.0
CHAR1718TT   5.0            0.0417       36.8       0.05       0.15       6.75     0.25
CHAR1719          5.0
CHAR1720          5.0
CHAR1721TT   5.0            0.0417       31.0       0.05       0.15       6.75     0.25
CHAR1722          5.0
CHAR1723          5.0
CHAR1724          5.0
CHAR1725          5.0
CHAR1726          5.0
CHAR1727          5.0
CHAR1728          5.0
CHAR1729          5.0
CHAR1730          5.0
CHAR1731          5.0
CHAR1732          5.0
CHAR1733          5.0
CHAR1734          5.0
CHAR1735          5.0
CHAR1736TT   5.0            0.0417        7.8       0.05       0.15       6.75     0.25
CHAR1737          5.0
CHAR1738          5.0
END
HTTF     21   .2        .01        5.      365.      100.      365.
HTTF     22   .2        .01        5.      365.      100.      365.
```

```
MTTF    23   .2      .01       6.      365.      100.      365.
MTTF    24   .2      .01       5.      365.      100.      365.
MTTF    25   .2      .01       3.      .3        100.      45.
MTTF    26   .01     .01       2.      .5        365.      365.
MTTF    27   .2      .01       5.      1.        137.      137.
MTTF    28   .01     .01       3.      3.        365.      365.
MTTF    29   .2      .01       3.      .3        100.      45.
MTTF    31    .2     .01       6.      365.      100.      365.
MTTF    32    .2     .01       6.      365.      100.      365.
MTTF    33    .2     .01       6.      365.      100.      365.
MTTF    34    .2     .01       5.      365.      100.      365.
MTTF    35    .2     .01       5.      365.      100.      365.
MTTF    36    .2     .01       3.      .3        100.      45.
MTTF    37    .2     .01       3.      .3        100.      45.
MTTF    38    .01    .01       2.      .5        365.      365.
MTTF    39    .2     .01       3.      .3        100.      45.
MTTF    40    .2     .01       5.      1.        137.      137.
MTTF    41    .01    .01       52.     52.          9999.     9999.
MTTF    42    .01    .01       3.      3.        365.      365.
MTTF    43    .2     .01       3.      .3        100.      45.
MTTF    44    .2     .01       5.      1.        137.      137.
MTTF    50    .2     .01       5.      1.        137.      137.
MTTF    51    .2     .01       3.      .3        100.      45.
MTTF    52     .2    .01       5.       1.      137.      137.
MTTF    53     .01    .01      2.       .5     365.      365.
END
SURV    30    05    1    1M22S02S03
SURV    30    05    2    1M50M28P03
SURV    30    05    3    2M29P02S04S05
SURV    30    05    4    2M26P05
SURV    30    05    5    3M53P04
END
AVAIL   30    05    1    1M22S02S03
AVAIL   30    05    2    1M50M28P03
AVAIL   30    05    3    2M29P02S04S05
AVAIL   30    05    4    2M26P05
AVAIL   30    05    5    3M53P04
END
SURV    21    10    1    1M31S02S03
SURV    21    10    2    1M44M41M42P03
SURV    21    10    3    2M43M38P02
END
AVAIL   21    10    1    1M31S02S03
AVAIL   21    10    2    1M44M41M42P03
AVAIL   21    10    3    2M43M38P02
END
SURV    09    11    1    1S02S03M32
SURV    09    11    2    1P03M40M41M42
SURV    09    11    3    2P02M39M38
SURV    21    11    1    1M33S02S03
SURV    21    11    2    1M44M41M42P03
SURV    21    11    3    2M43M38P02
SURV    30    11    1    1M23S02S03
SURV    30    11    2    1M50M28P03
SURV    30    11    3    2M29P02S04S05
SURV    30    11    4    2M26P05
SURV    30    11    5    3M53P04
END
AVAIL   09    11    1    1S02S03M32
AVAIL   09    11    2    1P03M40M41M42
AVAIL   09    11    3    2P02M39M38
AVAIL   21    11    1    1M33S02S03
AVAIL   21    11    2    1M44M41M42P03
AVAIL   21    11    3    2M43M38P02
AVAIL   30    11    1    1M23S02S03
AVAIL   30    11    2    1M50M28P03
AVAIL   30    11     3      2M29P02S04S05
AVAIL   30    11     4      2M26P05
AVAIL   30    11     5      3M53P04
END
SURV    02    17     1      1S02S03M34M38
SURV    02    17     2      1P03M37
SURV    02    17     3      2P02M36
SURV    18    17     1      1M21S02S03
SURV    18    17     2      1M27M28P03
SURV    18    17     3      2M25S04S05P02
SURV    18    17     4      2M26P05
SURV    18    17     5      3M53P04
SURV    21    17     1      1M35S02S03
SURV    21    17     2      1M44M41M42P03
SURV    21    17     3      2M43M38P02
SURV    36    17     1      1M24S02S03
SURV    36    17     2      1M52M28P03
SURV    36    17     3      2M51P02S04S05
SURV    36    17     4      2M26P05
SURV    36    17     5      3M53P04
END
AVAIL   02    17     1      1S02S03M34M38
AVAIL   02    17     2      1P03M37
AVAIL   02    17     3      2P02M36
AVAIL   18    17     1      1M21S02S03
AVAIL   18    17     2      1M27M28P03
AVAIL   18    17     3      2M25S04S05P02
AVAIL   18    17     4      2M26P05
AVAIL   18    17     5      3M53P04
AVAIL   21    17     1      1M35S02S03
AVAIL   21    17     2      1M44M41M42P03
AVAIL   21    17     3      2M43M38P02
AVAIL   36    17     1      1M24S02S03
AVAIL   36    17     2      1M52M28P03
AVAIL   36    17     3      2M51P02S04S05
AVAIL   36    17     4      2M26P05
AVAIL   36    17     5      3M53P04
END
COSTG    1  40000.    0.0       0.0        0.0         0
COSTG    2  10000.    5000.     0.0        0.0         1
COSTG    3  20000.    1000.     0.0        20000.      2
COSTG    4  5000.     2500.     500.       4500.       2
COSTG    5  1000.     150.      350.       150.        2
COSTG    6  1000.     150.      350.       150.        2
COSTG    7  1000.     150.      350.       150.        2
COSTG    8  10000.    5000.     0.0        0.0         1
COSTG    9  20000.    1000.     0.0        20000.      8
COSTG   10  5000.     2500.     500.       4500.       8
COSTG   11  1000.     150.      350.       150.        8
COSTG   12  1000.     150.      350.       150.        8
COSTG   13  1000.     150.      350.       150.        8
COSTM   21  1200.     200.      200.       900.       11
COSTM   22  800.      100.      50.        600.       12
COSTM   23  3500.     300.      350.       1800.      12
COSTM   24  1200.     200.      200.       900.       13
COSTM   25  1200.     20.       50.        900.       11
COSTM   26  3500.     300.      350.       1800.      10
COSTM   27  7000.     400.      1000.      5500.      11
COSTM   28  45000.    500.      1000.      35000.      9
COSTM   29  1200.     20.       50.        900.       12
COSTM   31  3500.     300.      350.       1800.       7
COSTM   32  3500.     300.      350.       1800.       6
COSTM   33  3500.     300.      350.       1800.       7
COSTM   34  1200.     200.       200.       900.       5
COSTM   35  1200.     200.       200.       900.       7
COSTM   36  1200.     20.        50.        900.       5
COSTM   37  1800.      20.       50.       1000.      5
COSTM   38  3000.      5000.     400.      2000.      4
COSTM   39  1200.      20.       50.       900.       6
COSTM   40  4500.      400.      900.      3800.      6
COSTM   41  0.         12000.    0.        0.         3
COSTM   42  40000.     400.      1000.     35000.     3
COSTM   43  1200.      20.       50.       900.       7
COSTM   44  4500.      400.      900.      3800.      7
COSTM   50  7000.      400.      1000.     5500.     12
COSTM   51  1200.      20.       50.       900.      13
COSTM   52  7000.      400.      1000.     5500.     13
COSTM   53  3000.      5000.     400.      2000.     13
END
#
```

CANDIDATE 2.0 RESULTS

```
DESIGN TYPE = F SYSTEM DUR. =    1.00 NO. OF MONTHS =    60 FLOW SCALING FACTORS =   1.0  5.0  2.0   .5   .3


 STA. NO.      STA. I.D.       SEG. NO.     SEG. ASSOCIATION



     1           3091500           5       1 2 3 4 5-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

     2           3094000           7       6 7 8 910-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

     3           3098000          25     212223242526-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

     4           3099500          29     2728293031-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

     5           3103500          13     1314151617181920-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

     6           3105500          33     323334-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

     7           3107500          36     35363738-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

     8           3095500          11     1112-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

PARAMETER NUMBER =   5

REACH NO. IMPL.   MN. PLCY.   CT      DELTA   IMPL. LOC.   EPSI      SEPSI     TUP      TDOWN


     1     F          F     1500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00

     2     F          F     1500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00

     3     F          F     1500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00

     4     F          F     1500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00

     5     F          F     1500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00

     6     F          F     1500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00

     7     F          F     1500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00

     8     F          F     1500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00

     9     F          F     1500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00

    10     F          F     1500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00

    11     F          F     1500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00

    12     F          F     1500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00

    13     F          F      500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00

    14     F          F      500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00

    15     F          F      500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00

    16     F          F      500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00

    17     F          F      500.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
 18    F       F    500.000  -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
 19    F       F    500.000  -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
 20    F       F    500.000  -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
 21    F       F   1500.000  -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
 22    F       F   1500.000  -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
 23    F       F   1500.000  -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
 24    F       F   1500.000  -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
 25    F       F   1500.000  -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
 26    F       F   1500.000  -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
 27    F       F   1500.000  -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
 28    F       F   1500.000  -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
 29    F       F   1500.000  -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
 30    T       T    500.000    .04     12.50    15.000  60.000   6.75    .25
 31    F       F    500.000  -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
 32    F       F    500.000  -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
 33    F       F    500.000  -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
 34    F       F    500.000  -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
 35    F       F    500.000  -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
 36    F       F    500.000  -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
 37    F       F    500.000  -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
 38    F       F    500.000  -0.00     -0.00    -0.000  -0.000  -0.00  -0.00

PARAMETER NUMBER =  10
REACH NO. IMPL.   MN. PLCY.   CT     DELTA   IMPL. LOC.   EPSI    SEPSI    TUP    TDOWN


      1    F         F       .005   -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
      2    F         F       .005   -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
      3    F         F       .005   -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
      4    F         F       .005   -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
      5    F         F       .005   -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
      6    F         F       .005   -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
      7    F         F       .005   -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
      8    F         F       .005   -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
      9    F         F       .005   -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
     10    F         F       .005   -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
     11    F         F       .005   -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
     12    F         F       .005   -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
     13    F         F      0.000   -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
     14    F         F      0.000   -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
     15    F         F      0.000   -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
     16    F         F      0.000   -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
     17    F         F      0.000   -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
     18    F         F      0.000   -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
     19    F         F      0.000   -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
     20    F         F      0.000   -0.00     -0.00    -0.000  -0.000  -0.00  -0.00
 21     T         T       .005    .04      31.00      .020    .150   6.75    .25
 22     F         F       .005  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 23     F         F       .005  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 24     F         F       .005  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 25     F         F       .005  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 26     F         F       .005  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 27     F         F       .005  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 28     F         F       .005  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 29     F         F       .005  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 30     F         F      0.000  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 31     F         F      0.000  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 32     F         F      0.000  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 33     F         F      0.000  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 34     F         F      0.000  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 35     F         F      0.000  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 36     F         F      0.000  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 37     F         F      0.000  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 38     F         F      0.000  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00

PARAMETER NUMBER =  11
REACH NO. IMPL.   MN. PLCY.   CT    DELTA   IMPL. LOC.   EPSI    SEPSI    TUP    TDOWN

  1     F         F       .100  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
  2     F         F       .100  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
  3     F         F       .100  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
  4     F         F       .100  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
  5     F         F       .100  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
  6     F         F       .100  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
  7     F         F       .100  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
  8     F         F       .100  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
  9     T         T       .100    .04      37.00      .001    .005   6.75    .25
 10     F         F       .100  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 11     F         F       .100  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 12     F         F       .100  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 13     F         F       .005  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 14     F         F       .005  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 15     F         F       .005  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 16     F         F       .005  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 17     F         F       .005  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 18     F         F       .005  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 19     F         F       .005  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 20     F         F       .005  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 21     T         T       .100    .04      31.00      .001    .005   6.75    .25
 22     F         F       .100  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 23     F         F       .100  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
 24     F         F       .100  -0.00      -0.00    -0.000  -0.000  -0.00  -0.00
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     25    F         F      .100  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     26    F         F      .100  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     27    F         F      .100  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     28    F         F      .100  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     29    F         F      .100  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     30    T         T      .005    .04     12.50       .001    .005   6.75    .25
     31    F         F      .005  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     32    F         F      .005  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     33    F         F      .005  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     34    F         F      .005  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     35    F         F      .005  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     36    F         F      .005  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     37    F         F      .005  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     38    F         F      .005  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00

PARAMETER NUMBER =  17
REACH NO. IMPL.   MN. PLCY.  CT     DELTA   IMPL. LOC.   EPSI    SEPSI   TUP    TDOWN


      1    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
      2    T         T      5.000    .04     82.50       .050    .150   6.75    .25
      3    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
      4    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
      5    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
      6    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
      7    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
      8    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
      9    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     10    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     11    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     12    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     13    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     14    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     15    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     16    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     17    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     18    T         T      5.000    .04     36.80       .050    .150   6.75    .25
     19    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     20    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     21    T         T      5.000    .04     31.00       .050    .150   6.75    .25
     22    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     23    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     24    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     25    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     26    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     27    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     28    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
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 29    F         F      5.000  -0.00    -0.00    -0.000  -0.000  -0.00  -0.00
 30    F         F      5.000  -0.00    -0.00    -0.000  -0.000  -0.00  -0.00
 31    F         F      5.000  -0.00    -0.00    -0.000  -0.000  -0.00  -0.00
 32    F         F      5.000  -0.00    -0.00    -0.000  -0.000  -0.00  -0.00
 33    F         F      5.000  -0.00    -0.00    -0.000  -0.000  -0.00  -0.00
 34    F         F      5.000  -0.00    -0.00    -0.000  -0.000  -0.00  -0.00
 35    F         F      5.000  -0.00    -0.00    -0.000  -0.000  -0.00  -0.00
 36    T         T      5.000    .04     7.80      .050    .150   6.75    .25
 37    F         F      5.000  -0.00    -0.00    -0.000  -0.000  -0.00  -0.00
 38    F         F      5.000  -0.00    -0.00    -0.000  -0.000  -0.00  -0.0


                 STATE 1 = OPERATING. STATE 2 = STAND-BY
MEANS NO..    MTTFS-1    MTTFS-2    MTTFA-1    MTTFA-2    MTTRA-1    MTTRA-2

    21          .20        .01        5.00      365.00     100.00     365.00
    22          .20        .01        5.00      365.00     100.00     365.00
    23          .20        .01        6.00      365.00     100.00     365.00
    24          .20        .01        5.00      365.00     100.00     365.00
    25          .20        .01        3.00         .30     100.00      45.00
    26          .01        .01        2.00         .50     365.00     365.00
    27          .20        .01        5.00        1.00     137.00     137.00
    28          .01        .01        3.00        3.00     365.00     365.00
    29          .20        .01        3.00         .30     100.00      45.00
    31          .20        .01        6.00      365.00     100.00     365.00
    32          .20        .01        6.00      365.00     100.00     365.00
    33          .20        .01        6.00      365.00     100.00     365.00
    34          .20        .01        5.00      365.00     100.00     365.00
    35          .20        .01        5.00      365.00     100.00     365.00
    36          .20        .01        3.00         .30     100.00      45.00
    37          .20        .01        3.00         .30     100.00      45.00
    38          .01        .01        2.00         .50     365.00     365.00
    39          .20        .01        3.00         .30     100.00      45.00
    40          .20        .01        5.00        1.00     137.00     137.00
    41          .01        .01       52.00       52.00    9999.00    9999.00
    42          .01        .01        3.00        3.00     365.00     365.00
    43          .20        .01        3.00         .30     100.00      45.00
    44          .20        .01        5.00        1.00     137.00     137.00
    50          .20        .01        5.00        1.00     137.00     137.00
    51          .20        .01        3.00         .30     100.00      45.00
    52          .20        .01        5.00        1.00     137.00     137.00
    53          .01        .01        2.00         .50     365.00     365.00


        PARAMETER NUMBER =  5 ELEMENT DESIGN FOR SURVIVABILITY

        REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN


           30         1             1        M22S 2S 3 -0 -0 -0 -0 -0 -0 -0
           30         2             1        M50M28P 3 -0 -0 -0 -0 -0 -0 -0
           30         3             2        M29P 2S 4S 5 -0 -0 -0 -0 -0 -0
           30         4             2        M26P 5 -0 -0 -0 -0 -0 -0 -0 -0
           30         5             3        M53P 4 -0 -0 -0 -0 -0 -0 -0 -0
        PARAMETER NUMBER =   5 ELEMENT DESIGN FOR AVAILABILITY

        REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN


           30         1             1        M22S 2S 3 -0 -0 -0 -0 -0 -0 -0
           30         2             1        M50M28P 3 -0 -0 -0 -0 -0 -0 -0
           30         3             2        M29P 2S 4S 5 -0 -0 -0 -0 -0 -0
           30         4             2        M26P 5 -0 -0 -0 -0 -0 -0 -0 -0
           30         5             3        M53P 4 -0 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                LUDATF     2
*** I M S L(UERTST) ***  WARNING                LEQTIF     2


PARAMETER NUMBER =   5

REACH NO. =  30 CAP =   7.63925E-03 SURV =   9.80935E-01 AVAIL =   9.99296E-01 ELEMENT EFF. =   7.48834E-03
```

```
        PARAMETER NUMBER = 10 ELEMENT DESIGN FOR SURVIVABILITY

        REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN


            21         1           1        M31S 2S 3 -0 -0 -0 -0 -0 -0 -0
            21         2           1        M44M41M42P 3 -0 -0 -0 -0 -0 -0
            21         3           2        M43M38P 2 -0 -0 -0 -0 -0 -0 -0
        PARAMETER NUMBER =  10 ELEMENT DESIGN FOR AVAILABILITY

        REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN


            21         1           1        M31S 2S 3 -0 -0 -0 -0 -0 -0 -0
            21         2           1        M44M41M42P 3 -0 -0 -0 -0 -0 -0
            21         3           2        M43M38P 2 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING               LUDATF     2
*** I M S L(UERTST) ***  WARNING               LEQT1F     2


PARAMETER NUMBER =  10

REACH NO. =  21 CAP =   3.36824E-02 SURV =   9.80095E-01 AVAIL =   9.78445E-01 ELEMENT EFF. =   3.23064E-02




        PARAMETER NUMBER = 11 ELEMENT UESIGN FOR SURVIVABILITY

        REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN


             9         1           1        S 2S 3M32 -0 -0 -0 -0 -0 -0 -0
             9         2           1        P 3M40M41M42 -0 -0 -0 -0 -0 -0
             9         3           2        P 2M39M38 -0 -0 -0 -0 -0 -0 -0
            21         1           1        M33S 2S 3 -0 -0 -0 -0 -0 -0 -0
            21         2           1        M44M41M42P 3 -0 -0 -0 -0 -0 -0
            21         3           2        M43M38P 2 -0 -0 -0 -0 -0 -0 -0
            30         1           1        M23S 2S 3 -0 -0 -0 -0 -0 -0 -0
            30         2           1        M50M28P 3 -0 -0 -0 -0 -0 -0 -0
            30         3           2        M29P 2S 4S 5 -0 -0 -0 -0 -0 -0 -0
            30         4           2        M26P 5 -0 -0 -0 -0 -0 -0 -0 -0
            30         5           3        M53P 4 -0 -0 -0 -0 -0 -0 -0 -0
        PARAMETER NUMBER =  11 ELEMENT DESIGN FOR AVAILABILITY

        REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN


             9         1           1        S 2S 3M32 -0 -0 -0 -0 -0 -0 -0
             9         2           1        P 3M40M41M42 -0 -0 -0 -0 -0 -0
             9         3           2        P 2M39M38 -0 -0 -0 -0 -0 -0 -0
            21         1           1        M33S 2S 3 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING               LUDATF     2
*** I M S L(UERTST) ***  WARNING               LEQT1F     2
            21         2           1        M44M41M42P 3 -0 -0 -0 -0 -0 -0
            21         3           2        M43M38P 2 -0 -0 -0 -0 -0 -0 -0
            30         1           1        M23S 2S 3 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING               LUDATF     2
*** I M S L(UERTST) ***  WARNING               LEQT1F     2
            30         2           1        M50M28P 3 -0 -0 -0 -0 -0 -0 -0
            30         3           2        M29P 2S 4S 5 -0 -0 -0 -0 -0 -0 -0
            30         4           2        M26P 5 -0 -0 -0 -0 -0 -0 -0 -0
            30         5           3        M53P 4 -0 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING               LUDATF     2
*** I M S L(UERTST) ***  WARNING               LEQT1F     2


PARAMETER NUMBER =  11

REACH NO. =   9 CAP -   3.62958E-02 SURV =   9.80095E-01 AVAIL =   9.78445E-01 ELEMENT EFF. =   3.48066E-02

REACH NO. =  21 CAP =   1.02833E-02 SURV =   9.80095E-01 AVAIL =   9.78445E-01 ELEMENT EFF. =   9.86135E-03

REACH NO. =  30 CAP =   8.73741E-03 SURV =   9.80935E-01 AVAIL =   9.99296E-01 ELEMENT EFF. =   8.56480E-03
```

```
PARAMETER NUMBER = 17 ELEMENT DESIGN FOR SURVIVABILITY

REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

    2          1            1         S 2S 3M34M38 -0 -0 -0 -0 -0 -0
    2          2            1         P 3M37 -0 -0 -0 -0 -0 -0 -0 -0
    2          3            2         P 2M36 -0 -0 -0 -0 -0 -0 -0 -0
   18          1            1         M21S 2S 3 -0 -0 -0 -0 -0 -0 -0
   18          2            1         M27M28P 3 -0 -0 -0 -0 -0 -0 -0
   18          3            2         M25S 4S 5P 2 -0 -0 -0 -0 -0 -0
   18          4            2         M26P 5 -0 -0 -0 -0 -0 -0 -0 -0
   18          5            3         M53P 4 -0 -0 -0 -0 -0 -0 -0 -0
   21          1            1         M35S 2S 3 -0 -0 -0 -0 -0 -0 -0
   21          2            1         M44M41M42P 3 -0 -0 -0 -0 -0 -0
   21          3            2         M43M38P 2 -0 -0 -0 -0 -0 -0 -0
   36          1            1         M24S 2S 3 -0 -0 -0 -0 -0 -0 -0
   36          2            1         M52M28P 3 -0 -0 -0 -0 -0 -0 -0
   36          3            2         M51P 2S 4S 5 -0 -0 -0 -0 -0 -0
   36          4            2         M26P 5 -0 -0 -0 -0 -0 -0 -0 -0
   36          5            3         M53P 4 -0 -0 -0 -0 -0 -0 -0 -0

PARAMETER NUMBER =  17 ELEMENT DESIGN FOR AVAILABILITY

REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

          2          1            1         S 2S 3M34M38 -0 -0 -0 -0 -0 -0
          2          2            1         P 3M37 -0 -0 -0 -0 -0 -0 -0
          2          3            2         P 2M36 -0 -0 -0 -0 -0 -0 -0
         18          1            1         M21S 2S 3 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                LUDATF      2
*** I M S L(UERTST) ***  WARNING                LEOT1F      2
         18          2            1         M27M28P 3 -0 -0 -0 -0 -0 -0
         18          3            2         M25S 4S 5P 2 -0 -0 -0 -0 -0
         18          4            2         M26P 5 -0 -0 -0 -0 -0 -0 -0
         18          5            3         M53P 4 -0 -0 -0 -0 -0 -0 -0
         21          1            1         M35S 2S 3 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                LUDATF      2
*** I M S L(UERTST) ***  WARNING                LEOT1F      2
         21          2            1         M44M41M42P 3 -0 -0 -0 -0 -0
         21          3            2         M43M38P 2 -0 -0 -0 -0 -0 -0
         36          1            1         M24S 2S 3 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                LUDATF      2
*** I M S L(UERTST) ***  WARNING                LEOT1F      2
         36          2            1         M52M28P 3 -0 -0 -0 -0 -0 -0
         36          3            2         M51P 2S 4S 5 -0 -0 -0 -0 -0
         36          4            2         M26P 5 -0 -0 -0 -0 -0 -0 -0
         36          5            3         M53P 4 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                LUDATF      2
*** I M S L(UERTST) ***  WARNING                LEOT1F      2

PARAMETER NUMBER =  17

REACH NO. =  2 CAP =  9.23774E-03 SURV =  7.95719E-01 AVAIL =  9.46683E-01 ELEMENT EFF. =  6.95873E-03

REACH NO. = 18 CAP =  3.14209E-02 SURV =  9.80935E-01 AVAIL =  9.99296E-01 ELEMENT EFF. =  3.08001E-02

REACH NO. = 21 CAP =  0.          SURV =  9.80095E-01 AVAIL =  9.78261E-01 ELEMENT EFF. =  0.

REACH NO. = 36 CAP =  3.03844E-02 SURV =  9.80935E-01 AVAIL =  9.99296E-01 ELEMENT EFF. =  2.97842E-02



SYSTEM EFFECTIVENESS =  2.92079E-01

TOTAL COST =  2.00490E+05

COST/EFF. =  6.86423E+05
```

CANDIDATE 1.1 DATA DECK

```
CONTROL F 001020011221011120     1.     60  1.    5.    2.    .5  .25      T
USGS     01  03091500 05 0102030405
USGS     02  03094000 07 0607080910
USGS     03  03098000 25 212223242526
USGS     04  03099500 29 2728293031
USGS     05  03103500 13 1314151617181920
USGS     06  03105500 33 323334
USGS     07  03107500 36 35363738
USGS     08  03095500 11 1112
END
```

"RIBAM SDD"

```
CHAR0501        1500.
CHAR0502        1500.
CHAR0503        1500.
CHAR0504        1500.
CHAR0505        1500.
CHAR0506        1500.
CHAR0507        1500.
CHAR0508        1500.
CHAR0509        1500.
CHAR0510        1500.
CHAR0511        1500.
CHAR0512        1500.
CHAR0513         500.
CHAR0514         500.
CHAR0515         500.
CHAR0516         500.
CHAR0517         500.
CHAR0518         500.
CHAR0519         500.
CHAR0520         500.
CHAR0521        1500.
CHAR0522        1500.
CHAR0523        1500.
CHAR0524        1500.
CHAR0525        1500.
CHAR0526        1500.
CHAR0527        1500.
CHAR0528        1500.
CHAR0529        1500.
CHAR0530TT       500.       3.5       11.0       15.0       15.0       365.       0.
CHAR0531         500.
CHAR0532         500.
CHAR0533         500.
CHAR0534         500.
CHAR0535         500.
CHAR0536         500.
CHAR0537         500.
CHAR0538         500.
END
CHAR1001         .005
CHAR1002         .005
CHAR1003         .005
CHAR1004         .005
CHAR1005         .005
CHAR1006         .005
CHAR1007         .005
CHAR1008         .005
CHAR1009         .005
CHAR1010         .005
CHAR1011         .005
CHAR1012         .005
```

```
CHAR1013        .0
CHAR1014        .0
CHAR1015        .0
CHAR1016        .0
CHAR1017        .0
CHAR1018        .0
CHAR1019        .0
CHAR1020        .0
CHAR1021TT     .005       3.5       30.6       0.05       0.10       365.       0.
CHAR1022        .005
CHAR1023        .005
CHAR1024        .005
CHAR1025        .005
CHAR1026        .005
CHAR1027        .005
CHAR1028        .005
CHAR1029        .005
CHAR1030        .0
CHAR1031        .0
CHAR1032       0.00
CHAR1033       0.0
CHAR1034       0.0
CHAR1035       0.00
CHAR1036       0.0
CHAR1037       0.0
CHAR1038       0.0
END
CHAR1101          0.1
CHAR1102          0.1
CHAR1103          0.1
CHAR1104          0.1
CHAR1105          0.1
CHAR1106          0.1
CHAR1107          0.1
CHAR1108          0.1
CHAR1109TT       0.1      7.        37.0       .001       .002       365.       0.
CHAR1110          0.1
CHAR1111          0.1
CHAR1112          0.1
CHAR1113       0.005
CHAR1114       0.005
CHAR1115       0.005
CHAR1116       0.005
CHAR1117       0.005
CHAR1118       0.005
CHAR1119       0.005
CHAR1120       0.005
CHAR1121         0.1      7.0       30.6      0.001      0.002       365.       0.
CHAR1122          0.1
CHAR1123          0.1
CHAR1124          0.1
CHAR1125          0.1
CHAR1126          0.1
CHAR1127          0.1
CHAR1128          0.1
CHAR1129          0.1
CHAR1130TT     0.005      3.5       11.0      0.001      0.002       365.       0.
CHAR1131       0.005
CHAR1132       0.005
CHAR1133       0.005
CHAR1134       0.005
CHAR1135       0.005
CHAR1136       0.005
CHAR1137       0.005
CHAR1138     0.005
END
```

```
CHAR1701          5.0
CHAR1702TT      5.0       90.         82.5        0.02        0.10        365.      0.
CHAR1703          5.0
CHAR1704          5.0
CHAR1705          5.0
CHAR1706          5.0
CHAR1707          5.0
CHAR1708          5.0
CHAR1709          5.0
CHAR1710      5.0
CHAR1711          5.0
CHAR1712          5.0
CHAR1713          5.0
CHAR1714          5.0
CHAR1715          5.0
CHAR1716          5.0
CHAR1717          5.0
CHAR1718TT      5.0       7.          36.8        0.02       0.10        365.        0.
CHAR1719          5.0
CHAR1720          5.0
CHAR1721TT      5.0       3.5         30.6       0.02        0.10        365.       0.
CHAR1722          5.0
CHAR1723          5.0
CHAR1724          5.0
CHAR1725          5.0
CHAR1726          5.0
CHAR1727          5.0
CHAR1728          5.0
CHAR1729          5.0
CHAR1730          5.0
CHAR1731          5.0
CHAR1732          5.0
CHAR1733          5.0
CHAR1734          5.0
CHAR1735          5.0
CHAR1736TT      5.0        7.0        4.0        0.02        0.10          365.        0.
CHAR1737          5.0
CHAR1738          5.0
END
MTTF     01          0.2       0.01        2.0        1.0       365.       365.
MTTF     02         0.01       0.01        2.0       0.01       365.       365.
MTTF     03         0.01       0.01        2.0       0.01       365.       365.
MTTF     04          0.2       0.01        4.0        2.0       365.       365.
MTTF     05         0.02       0.02        4.0        0.1        52.        52.
MTTF     06          0.2       0.01        2.0        1.0       365.       365.
MTTF     07         0.01       0.01        2.0       0.01       365.       365.
MTTF     08         0.01       0.01        2.0       0.01       365.       365.
MTTF     09          0.2       0.01        4.0        2.0       365.       365.
MTTF     10          0.2       0.01        2.0        1.0       365.       365.
MTTF     11         0.01       0.01        2.0       0.01       365.       365.
MTTF     12          0.2       0.01        4.0        2.0       365.       365.
MTTF     13          0.2       0.01        4.0        2.0       365.       365.
MTTF     14         0.02       0.02        4.0        0.1        52.        52.
MTTF     15          0.2       0.01        2.0        1.0       365.       365.
MTTF     16         0.01       0.01        2.0        .01       365.       365.
MTTF     17          0.2       0.01        4.0        2.0       365.       365.
MTTF     18          0.2       0.01        4.0        2.0       365.       365.
MTTF     19          0.2        0.1        4.0        1.0       122.       122.
END
SURV     30    05    1     1S02S03
SURV     30    05    2     1M10M13P03
SURV     30    05    3     2M15M18P02
END
AVAIL    30    05    1     1S02S03
AVAIL    30    05    2     1M10M13P03
AVAIL    30    05    3     2M15M18P02
END
```

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SURV     21    10     1     1S02S03
SURV     21    10     2     1M01M02P03
SURV     21    10     3     2M06M07P02
END
AVAIL    21    10     1     1S02S03
AVAIL    21    10     2     1M01M02P03
AVAIL    21    10     3     2M06M07P02
END
SURV     09    11     1     1M05S02S03
SURV     09    11     2     1M01M03P03
SURV     09    11     3     2M06M08P02
SURV     21    11     1     1S02S03M05
SURV     21    11     2     1M01M03P03
SURV     21    11     3     2M06M08P02
SURV     30    11     1     1M14S02S03
SURV     30    11     2     1M10M11P03
SURV     30    11     3     2M15M16P02
END
AVAIL    09    11     1     1M05S02S03
AVAIL    09    11     2     1M01M03P03
AVAIL    09    11     3     2M06M08P02
AVAIL    21    11     1     1S02S03M05
AVAIL    21    11     2     1M01M03P03
AVAIL    21    11     3     2M06M08P02
AVAIL    30    11     1     1M14S02S03
AVAIL    30    11     2     1M10M11P03
AVAIL    30    11     3     2M15M16P02
END
SURV     02    17     1     1S02S03M14
SURV     02    17     2     1M01M04P03
SURV     02    17     3     2M06M09P02
SURV     18    17     1     1S02S03
SURV     18    17     2     1M10M12P03
SURV     18    17     3     2M15M17P02
SURV     21    17     1     1S02S03
SURV     21    17     2     1M01M04P03
SURV     21    17     3     2M06M09P02
SURV     36    17     1     1S02S03
SURV     36    17     2     1M10M12P03
SURV     36    17     3     2M15M17P02
END
AVAIL    02    17     1     1S02S03M19
AVAIL    02    17     2     1M01M04P03
AVAIL    02    17     3     2M06M09P02
AVAIL    18    17     1     1S02S03
AVAIL    18    17     2     1M10M12P03
AVAIL    18    17     3     2M15M17P02
AVAIL    21    17     1     1S02S03
AVAIL    21    17     2     1M01M04P03
AVAIL    21    17     3     2M06M09P02
AVAIL    36    17     1     1S02S03
AVAIL    36    17     2     1M10M12P03
AVAIL    36    17     3     2M15M17P02
END
COSTG     1     40000.        0.        0.        0.    0
COSTG     2     10000.     5000.        0.        0.    1
COSTG     3     20000.     4500.     1000.    20000.    2
COSTG     4      5000.     2500.      500.     4500.    2
COSTG     5     10000.     5000.        0.        0.    1
COSTG     6     20000.     4500.     1000.    20000.    5
COSTG     7      5000.     1500.      250.     4500.    5
COSTG     8      5000.     1500.      250.     4500.    5
COSTM     1      3000.  10000.     600.      2000.        4
COSTM     2       400.  1000.      0.        0.           4
COSTM     3       400.      500.        0.        0.    4
COSTM     4       600.   20.        200.      300.      4
COSTM     5      1500.       50.        0.     1500.    3
COSTM    6     3000.  1000.      400.      2000.      4
COSTM    7      400.  50.            0.          0.   4
COSTM    8      400.   50.           0.          0.   4
COSTM    9      600.  5.         50.       300.       4
COSTM   10     3000.  7000.      400.      2000.      7
COSTM   11      400.  1000.      0.        0.         7
COSTM   12      600.        10.       100.       300.  7
COSTM   13      300.    20.       100.       150.     7
COSTM   14     1500.        50.          0.      1500. 6
COSTM   15     3000.   1000.         400.    2000.    8
COSTM   16      400.   50.             0.        0.   8
COSTM   17      600.        10.      100.       300.  8
COSTM   18      300.        10.       50.       150.  8
COSTM   19     1500.   200.        100.     1000.     4
END
#
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CANDIDATE 1.1 RESULTS

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DESIGN TYPE = F SYSTEM DUR. =    1.00 NO. OF MONTHS =    60 FLOW SCALING FACTORS =   1.0  5.0  2.0   .5   .3


 STA. NO.      STA. I.D.       SEG. NO.     SEG. ASSOCIATION


     1           3091500            5      1 2 3 4 5-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

     2           3094000            7      6 7 8 910-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

     3           3098000           25     212223242526-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

     4           3099500           29     2728293031-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

     5           3103500           13     1314151617181920-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

     6           3105500           33     323334-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

     7           3107500           36     35363738-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

     8           3095500           11     1112-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

PARAMETER NUMBER =    5

REACH NO. IMPL.    MN. PLCY.   CT      DELTA   IMPL. LOC.   EPSI      SEPSI     TUP      TDOWN


     1      F          F     1500.000  -0.00     -0.00     -0.000    -0.000    -0.00    -0.00

     2      F          F     1500.000  -0.00     -0.00     -0.000    -0.000    -0.00    -0.00

     3      F          F     1500.000  -0.00     -0.00     -0.000    -0.000    -0.00    -0.00

     4      F          F     1500.000  -0.00     -0.00     -0.000    -0.000    -0.00    -0.00

     5      F          F     1500.000  -0.00     -0.00     -0.000    -0.000    -0.00    -0.00

     6      F          F     1500.000  -0.00     -0.00     -0.000    -0.000    -0.00    -0.00

     7      F          F     1500.000  -0.00     -0.00     -0.000    -0.000    -0.00    -0.00

     8      F          F     1500.000  -0.00     -0.00     -0.000    -0.000    -0.00    -0.00

     9      F          F     1500.000  -0.00     -0.00     -0.000    -0.000    -0.00    -0.00

    10      F          F     1500.000  -0.00     -0.00     -0.000    -0.000    -0.00    -0.00

    11      F          F     1500.000  -0.00     -0.00     -0.000    -0.000    -0.00    -0.00

    12      F          F     1500.000  -0.00     -0.00     -0.000    -0.000    -0.00    -0.00

    13      F          F      500.000  -0.00     -0.00     -0.000    -0.000    -0.00    -0.00

    14      F          F      500.000  -0.00     -0.00     -0.000    -0.000    -0.00    -0.00

    15      F          F      500.000  -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
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   16     F          F     500.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   17     F          F     500.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   18     F          F     500.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   19     F          F     500.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   20     F          F     500.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   21     F          F    1500.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   22     F          F    1500.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   23     F          F    1500.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   24     F          F    1500.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   25     F          F    1500.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   26     F          F    1500.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   27     F          F    1500.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   28     F          F    1500.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   29     F          F    1500.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   30     T          T     500.000    3.50      11.00      15.000   15.000  365.00    0.00
   31     F          F     500.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   32     F          F     500.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   33     F          F     500.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   34     F          F     500.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   35     F          F     500.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   36     F          F     500.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   37     F          F     500.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   38     F          F     500.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
PARAMETER NUMBER =  10
REACH NO. IMPL.   MN. PLCY.  CT     DELTA    IMPL. LOC.   EPSI     SEPSI    TUP     TDOWN


    1     F          F          .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    2     F          F          .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    3     F          F          .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    4     F          F          .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    5     F          F          .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    6     F          F          .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    7     F          F          .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    8     F          F          .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    9     F          F          .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   10     F          F          .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   11     F          F          .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   12     F          F          .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   13     F          F         0.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   14     F          F         0.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   15     F          F         0.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   16     F          F         0.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   17     F          F         0.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   18     F          F         0.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
   19     F          F         0.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
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      20     F          F       0.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      21     T          T        .005    3.50      30.60        .050     .100  365.00    0.00
      22     F          F        .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      23     F          F        .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      24     F          F        .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      25     F          F        .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      26     F          F        .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      27     F          F        .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      28     F          F        .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      29     F          F        .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      30     F          F       0.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      31     F          F       0.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      32     F          F       0.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      33     F          F       0.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      34     F          F       0.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      35     F          F       0.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      36     F          F       0.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      37     F          F       0.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      38     F          F       0.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
PARAMETER NUMBER =  11
REACH NO. IMPL.    MN. PLCY.    CT      DELTA    IMPL. LOC.    EPSI     SEPSI     TUP     TDOWN


       1     F          F        .100   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
       2     F          F        .100   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
       3     F          F        .100   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
       4     F          F        .100   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
       5     F          F        .100   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
       6     F          F        .100   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
       7     F          F        .100   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
       8     F          F        .100   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
       9     T          T        .100    7.00      37.00        .001     .002  365.00    0.00
      10     F          F        .100   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      11     F          F        .100   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      12     F          F        .100   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      13     F          F        .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      14     F          F        .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      15     F          F        .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      16     F          F        .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      17     F          F        .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      18     F          F        .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      19     F          F        .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      20     F          F        .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      21     F          F        .100    7.00      30.60        .001     .002  365.00    0.00
      22     F          F        .100   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
      23     F          F        .100   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
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    24     F         F       .100   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    25     F         F       .100   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    26     F         F       .100   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    27     F         F       .100   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    28     F         F       .100   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    29     F         F       .100   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    30     T         T       .005    3.50     11.00       .001      .002  365.00     0.00
    31     F         F       .005   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    32     F         F       .005   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    33     F         F       .005   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    34     F         F       .005   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    35     F         F       .005   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    36     F         F       .005   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    37     F         F       .005   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    38     F         F       .005   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
PARAMETER NUMBER =  17
REACH NO. IMPL.   MN. PLCY.   CT     DELTA   IMPL. LOC.   EPSI     SEPSI     TUP     TDOWN


     1     F         F      5.000   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
     2     T         T      5.000   90.00     42.50       .020      .100  365.00     0.00
     3     F         F      5.000   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
     4     F         F      5.000   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
     5     F         F      5.000   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
     6     F         F      5.000   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
     7     F         F      5.000   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
     8     F         F      5.000   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
     9     F         F      5.000   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    10     F         F      5.000   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    11     F         F      5.000   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    12     F         F      5.000   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    13     F         F      5.000   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    14     F         F      5.000   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    15     F         F      5.000   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    16     F         F      5.000   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    17     F         F      5.000   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    18     T         T      5.000    7.00     36.80       .020      .100  365.00     0.00
    19     F         F      5.000   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    20     F         F      5.000   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    21     T         T      5.000    3.50     30.60       .020      .100  365.00     0.00
    22     F         F      5.000   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    23     F         F      5.000   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    24     F         F      5.000   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    25     F         F      5.000   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    26     F         F      5.000   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
    27     F         F      5.000   -0.00     -0.00     -0.000    -0.000   -0.00    -0.00
```

```
28    F       F      5.000  -0.00    -0.00    -0.000  -0.000  -0.00  -0.00
29    F       F      5.000  -0.00    -0.00    -0.000  -0.000  -0.00  -0.00
30    F       F      5.000  -0.00    -0.00    -0.000  -0.000  -0.00  -0.00
31    F       F      5.000  -0.00    -0.00    -0.000  -0.000  -0.00  -0.00
32    F       F      5.000  -0.00    -0.00    -0.000  -0.000  -0.00  -0.00
33    F       F      5.000  -0.00    -0.00    -0.000  -0.000  -0.00  -0.00
34    F       F      5.000  -0.00    -0.00    -0.000  -0.000  -0.00  -0.00
35    F       F      5.000  -0.00    -0.00    -0.000  -0.000  -0.00  -0.00
36    T       T      5.000   7.00     4.00      .020    .100 365.00   0.00
37    F       F      5.000  -0.00    -0.00    -0.000  -0.000  -0.00  -0.00
38    F       F      5.000  -0.00    -0.00    -0.000  -0.000  -0.00  -0.00
```

```
               STATE 1 = OPFRATING, STATE 2 = STAND-BY
MEANS NO..    MTTFS-1    MTTFS-2    MTTFA-1    MTTFA-2   MTTRA-1    MTTRA-2

     1          .20        .01       2.00       1.00     365.00     365.00
     2          .01        .01       2.00        .01     365.00     365.00
     3          .01        .01       2.00        .01     365.00     365.00
     4          .20        .01       4.00       2.00     365.00     365.00
     5          .02        .02       4.00        .10      52.00      52.00
     6          .20        .01       2.00       1.00     365.00     365.00
     7          .01        .01       2.00        .01     365.00     365.00
     8          .01        .01       2.00        .01     365.00     365.00
     9          .20        .01       4.00       2.00     365.00     365.00
    10          .20        .01       2.00       1.00     365.00     365.00
    11          .01        .01       2.00        .01     365.00     365.00
    12          .20        .01       4.00       2.00     365.00     365.00
    13          .20        .01       4.00       2.00     365.00     365.00
    14          .02        .02       4.00        .10      52.00      52.00
    15          .20        .01       2.00       1.00     365.00     365.00
    16          .01        .01       2.00        .01     365.00     365.00
    17          .20        .01       4.00       2.00     365.00     365.00
    18          .20        .01       4.00       2.00     365.00     365.00
    19          .20        .10       4.00       1.00     122.00     122.00
```

```
      PARAMETER NUMBER =  5 ELEMENT DESIGN FOR SURVIVABILITY

      REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

          30         1            1        S 2S 3 -0 -0 -0 -0 -0 -0 -0
          30         2            1        M10M13P 3 -0 -0 -0 -0 -0 -0
          30         3            2        M15M1AP 2 -0 -0 -0 -0 -0 -0

      PARAMETER NUMBER =   5 ELEMENT DESIGN FOR AVAILABILITY

      REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

          30         1            1        S 2S 3 -0 -0 -0 -0 -0 -0 -0
          30         2            1        M10M13P 3 -0 -0 -0 -0 -0 -0
          30         3            2        M15M1AP 2 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                  LUDATF     2
*** I M S L(UERTST) ***  WARNING                  LEQT1F     2

PARAMETER NUMBER =   5

REACH NO. =  30 CAP =   5.55287E-03 SURV =   9.35785E-01 AVAIL =   9.99801E-01 ELEMENT EFF. =   5.19525E-03
```

```
        PARAMETER NUMBER = 10 ELEMENT DESIGN FOR SURVIVABILITY

        REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

            21        1           1         S 2S 3 -0 -0 -0 -0 -0 -0 -0
            21        2           1         M 1M 2P 3 -0 -0 -0 -0 -0 -0 -0
            21        3           2         M 6M 7P 2 -0 -0 -0 -0 -0 -0 -0
        PARAMETER NUMBER =  10 ELEMENT DESIGN FOR AVAILABILITY

        REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

            21        1           1         S 2S 3 -0 -0 -0 -0 -0 -0 -0
            21        2           1         M 1M 2P 3 -0 -0 -0 -0 -0 -0 -0
            21        3           2         M 6M 7P 2 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                LUDATF     2
*** I M S L(UERTST) ***  WARNING                LEQT1F     2

PARAMETER NUMBER =  10

REACH NO. =  21 CAP =   2.53191E-02 SURV =   9.79116E-01 AVAIL =   9.99925E-01 ELEMENT EFF. =   2.47885E-02




        PARAMETER NUMBER = 11 ELEMENT DESIGN FOR SURVIVABILITY

        REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

             9        1           1         M 5S 2S 3 -0 -0 -0 -0 -0 -0 -0
             9        2           1         M 1M 3P 3 -0 -0 -0 -0 -0 -0 -0
             9        3           2         M 6M 8P 2 -0 -0 -0 -0 -0 -0 -0
            21        1           1         S 2S 3M 5 -0 -0 -0 -0 -0 -0 -0
            21        2           1         M 1M 3P 3 -0 -0 -0 -0 -0 -0 -0
            21        3           2         M 6M 8P 2 -0 -0 -0 -0 -0 -0 -0
            30        1           1         M14S 2S 3 -0 -0 -0 -0 -0 -0 -0
            30        2           1         M10M11P 3 -0 -0 -0 -0 -0 -0 -0
            30        3           2         M15M16P 2 -0 -0 -0 -0 -0 -0 -0
        PARAMETER NUMBER =  11 ELEMENT DESIGN FOR AVAILABILITY

        REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

             9        1           1         M 5S 2S 3 -0 -0 -0 -0 -0 -0 -0
             9        2           1         M 1M 3P 3 -0 -0 -0 -0 -0 -0 -0
             9        3           2         M 6M 8P 2 -0 -0 -0 -0 -0 -0 -0
            21        1           1         S 2S 3M 5 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                LUDATF     2
*** I M S L(UERTST) ***  WARNING                LEQT1F     2
            21        2           1         M 1M 3P 3 -0 -0 -0 -0 -0 -0 -0
            21        3           2         M 6M 8P 2 -0 -0 -0 -0 -0 -0 -0
            30        1           1         M14S 2S 3 -0 -0 -0 -0 -0 -0 -0
            30        2           1         M10M11P 3 -0 -0 -0 -0 -0 -0 -0
            30        3           2         M15M16P 2 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                LUDATF     2
*** I M S L(UERTST) ***  WARNING                LEQT1F     2

PARAMETER NUMBER =  11

REACH NO. =   9 CAP =   1.95188E-02 SURV =   9.59728E-01 AVAIL =   9.28502E-01 ELEMENT EFF. =   1.73934E-02

REACH NO. =  30 CAP =   6.99460E-03 SURV =   9.59728E-01 AVAIL =   9.28502E-01 ELEMENT EFF. =   6.23303E-03
```

```
PARAMETER NUMBER = 17 ELEMENT DESIGN FOR SURVIVABILITY

REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

                                      S 2S 3M19 -0 -0 -0 -0 -0 -0 -0
   2         1              1         M 1M 4P 3 -0 -0 -0 -0 -0 -0 -0
   2         2              1         M 6M 9P 2 -0 -0 -0 -0 -0 -0 -0
   2         3              2         S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
  18         1              1         M10M12P 3 -0 -0 -0 -0 -0 -0 -0
  18         2              1         M15M17P 2 -0 -0 -0 -0 -0 -0 -0
  18         3              2         S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
  21         1              1         M 1M 4P 3 -0 -0 -0 -0 -0 -0 -0
  21         2              1         M 6M 9P 2 -0 -0 -0 -0 -0 -0 -0
  21         3              2         S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
  36         1              1         M10M12P 3 -0 -0 -0 -0 -0 -0 -0
  36         2              1         M15M17P 2 -0 -0 -0 -0 -0 -0 -0
  36         3              2
 PARAMETER NUMBER =  17 ELEMENT DESIGN FOR AVAILABILITY

 REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

                                       S 2S 3M19 -0 -0 -0 -0 -0 -0 -0
       2         1              1      M 1M 4P 3 -0 -0 -0 -0 -0 -0 -0
       2         2              1      M 6M 9P 2 -0 -0 -0 -0 -0 -0 -0
       2         3              2      S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
      18         1              1         LUDATF     2
*** I M S L(UERTST) ***  WARNING          LEQT1F     2
*** I M S L(UERTST) ***  WARNING       M10M12P 3 -0 -0 -0 -0 -0 -0 -0
      18         2              1      M15M17P 2 -0 -0 -0 -0 -0 -0 -0
      18         3              2      S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
      21         1              1         LUDATF     2
*** I M S L(UERTST) ***  WARNING          LEQT1F     2
*** I M S L(UERTST) ***  WARNING       M 1M 4P 3 -0 -0 -0 -0 -0 -0 -0
      21         2              1      M 6M 9P 2 -0 -0 -0 -0 -0 -0 -0
      21         3              2      S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
      36         1              1         LUDATF     2
*** I M S L(UERTST) ***  WARNING          LEQT1F     2
*** I M S L(UERTST) ***  WARNING       M10M12P 3 -0 -0 -0 -0 -0 -0 -0
      36         2              1      M15M17P 2 -0 -0 -0 -0 -0 -0 -0
      36         3              2         LUDATF     2
*** I M S L(UERTST) ***  WARNING          LEQT1F     2
*** I M S L(UERTST) ***  WARNING

PARAMETER NUMBER =  17

REACH NO. =   2 CAP =   2.57711E-04 SURV =   7.66156E-01 AVAIL =   9.68061E-01 ELEMENT EFF. =   1.91140E-04

REACH NO. =  18 CAP =   1.71128E-02 SURV =   9.35785E-01 AVAIL =   9.99801E-01 ELEMENT EFF. =   1.60107E-02

REACH NO. =  21 CAP =   2.66354E-02 SURV =   9.35785E-01 AVAIL =   9.99801E-01 ELEMENT EFF. =   2.49200E-02

REACH NO. =  36 CAP =   1.74748E-02 SURV =   9.35785E-01 AVAIL =   9.99801E-01 ELEMENT EFF. =   1.63494E-02




 SYSTEM EFFECTIVENESS =   2.02066E-01

TOTAL COST =   1.61925E+05

COST/EFF. =   8.01347E+05
```

CANDIDATE 2.1 DATA DECK

```
CONTROL F 001020011221011120     1.     60  1.    5.    2.    .5  .25      T
USGS     01  03091500 05 0102030405
USGS     02  03094000 07 0607080910
USGS     03  03098000 25 212223242526
USGS     04  03099500 29 2728293031
USGS     05  03103500 13 13141516171819 20
USGS     06  03105500 33 323334
USGS     07  03107500 36 35363738
USGS     08  03095500 11 1112
END
```

"RIBAM SDD"

```
CHAR0501         1500.
CHAR0502         1500.
CHAR0503         1500.
CHAR0504         1500.
CHAR0505         1500.
CHAR0506         1500.
CHAR0507         1500.
CHAR0508         1500.
CHAR0509         1500.
CHAR0510         1500.
CHAR0511         1500.
CHAR0512         1500.
CHAR0513          500.
CHAR0514          500.
CHAR0515          500.
CHAR0516          500.
CHAR0517          500.
CHAR0518          500.
CHAR0519          500.
CHAR0520          500.
CHAR0521         1500.
CHAR0522         1500.
CHAR0523         1500.
CHAR0524         1500.
CHAR0525         1500.
CHAR0526         1500.
CHAR0527         1500.
CHAR0528         1500.
CHAR0529         1500.
CHAR0530TT    500.           0.0417       12.5        15.0        60.0        6.75     0.25
CHAR0531          500.
CHAR0532          500.
CHAR0533          500.
CHAR0534          500.
CHAR0535          500.
CHAR0536          500.
CHAR0537          500.
CHAR0538          500.
END
CHAR1001          .005
CHAR1002          .005
CHAR1003          .005
CHAR1004          .005
CHAR1005          .005
CHAR1006          .005
CHAR1007          .005
CHAR1008          .005
CHAR1009          .005
CHAR1010          .005
CHAR1011          .005
```

```
CHAR1012         .005
CHAR1013         .0
CHAR1014         .0
CHAR1015         .0
CHAR1016         .0
CHAR1017         .0
CHAR1018         .0
CHAR1019         .0
CHAR1020         .0
CHAR1021TT    .005         0.0417       31.0        0.02        0.15        6.75      0.25
CHAR1022         .005
CHAR1023         .005
CHAR1024         .005
CHAR1025         .005
CHAR1026         .005
CHAR1027         .005
CHAR1028         .005
CHAR1029         .005
CHAR1030         .0
CHAR1031         .0
CHAR1032        0.00
CHAR1033        0.0
CHAR1034        0.0
CHAR1035        0.00
CHAR1036        0.0
CHAR1037        0.0
CHAR1038        0.0
END
CHAR1101           0.1
CHAR1102           0.1
CHAR1103           0.1
CHAR1104           0.1
CHAR1105           0.1
CHAR1106           0.1
CHAR1107           0.1
CHAR1108           0.1
CHAR1109TT    0.1          0.0417       37.00       .001        .005        6.75      0.25
CHAR1110           0.1
CHAR1111           0.1
CHAR1112           0.1
CHAR1113        0.005
CHAR1114        0.005
CHAR1115        0.005
CHAR1116        0.005
CHAR1117        0.005
CHAR1118        0.005
CHAR1119        0.005
CHAR1120        0.005
CHAR1121TT    0.1          0.0417       31.0        .001        .005        6.75      0.25
CHAR1122           0.1
CHAR1123           0.1
CHAR1124           0.1
CHAR1125           0.1
CHAR1126           0.1
CHAR1127           0.1
CHAR1128           0.1
CHAR1129           0.1
CHAR1130TT   0.005         0.0417       12.5        .001        .005        6.75      0.25
CHAR1131        0.005
CHAR1132        0.005
CHAR1133        0.005
CHAR1134        0.005
CHAR1135        0.005
CHAR1136        0.005
CHAR1137        0.005
CHAR1138     0.005
END
```

```
CHAR1701           5.0
CHAR1702TT    5.0          0.0417       82.5       0.05       0.15       6.75     0.25
CHAR1703           5.0
CHAR1704           5.0
CHAR1705           5.0
CHAR1706           5.0
CHAR1707           5.0
CHAR1708           5.0
CHAR1709           5.0
CHAR1710TT    5.0          0.0417       31.0       0.05       0.15       6.75     0.25
CHAR1711           5.0
CHAR1712           5.0
CHAR1713           5.0
CHAR1714           5.0
CHAR1715           5.0
CHAR1716           5.0
CHAR1717           5.0
CHAR1718TT    5.0          0.0417       36.8       0.05       0.15       6.75     0.25
CHAR1719           5.0
CHAR1720           5.0
CHAR1721      5.0
CHAR1722           5.0
CHAR1723           5.0
CHAR1724           5.0
CHAR1725           5.0
CHAR1726           5.0
CHAR1727           5.0
CHAR1728           5.0
CHAR1729           5.0
CHAR1730           5.0
CHAR1731           5.0
CHAR1732           5.0
CHAR1733           5.0
CHAR1734           5.0
CHAR1735           5.0
CHAR1736TT    5.0          0.0417        7.8       0.05       0.15       6.75     0.25
CHAR1737           5.0
CHAR1738           5.0
END
MTTF      21   .2         .01        5.       365.        100.       365.
MTTF      22   .2         .01        5.       365.        100.       365.
MTTF      23   .2         .01        6.       365.        100.       365.
MTTF      24   .2         .01        5.       365.        100.       365.
MTTF      25   .2         .01        3.       .3          100.       45.
MTTF      26   .01        .01        2.       .5          365.       365.
MTTF      27   .2         .01        5.       1.          137.       137.
MTTF      28   .01        .01        3.       3.          365.       365.
MTTF      29   .2         .01        3.       .3          100.       45.
MTTF      31    .2        .01        6.       365.        100.       365.
MTTF      32    .2        .01        6.       365.        100.       365.
MTTF      33    .2        .01        6.       365.        100.       365.
MTTF      34    .2        .01        5.       365.        100.       365.
MTTF      35    .2        .01        5.       365.        100.       365.
MTTF      36    .2        .01        3.       .3          100.       45.
MTTF      37    .2        .01        3.       .3          100.       45.
MTTF      38    .01       .01        2.       .5          365.       365.
MTTF      39    .2        .01        3.       .3          100.       45.
MTTF      40    .2        .01        5.       1.          137.       137.
MTTF      41    .01       .01        52.      52.          9999.      9999.
MTTF      42    .01       .01        3.       3.          365.       365.
MTTF      43    .2        .01        3.       .3          100.       45.
MTTF      44    .2        .01        5.       1.          137.       137.
MTTF      50    .2        .01        5.       1.          137.       137.
MTTF      51    .2        .01        3.       .3          100.       45.
MTTF      52     .2       .01        5.        1.        137.      137.
MTTF      53     .01       .01       2.        .5        365.      365.
```

```
END
SURV    30   05   1    1M22S02S03
SURV    30   05   2    1M50M28P03
SURV    30   05   3    2M29P02S04S05
SURV    30   05   4    2M26P05
SURV    30   05   5    3M53P04
END
AVAIL   30   05   1    1M22S02S03
AVAIL   30   05   2    1M50M28P03
AVAIL   30   05   3    2M29P02S04S05
AVAIL   30   05   4    2M26P05
AVAIL   30   05   5    3M53P04
END
SURV    21   10   1    1M31S02S03
SURV    21   10   2    1M44M41M42P03
SURV    21   10   3    2M43M38P02
END
AVAIL   21   10   1    1M31S02S03
AVAIL   21   10   2    1M44M41M42P03
AVAIL   21   10   3    2M43M38P02
END
END
AVAIL   21   10   1    1M31S02S03
AVAIL   21   10   2    1M44M41M42P03
AVAIL   21   10   3    2M43M38P02
END
SURV    09   11   1    1S02S03M32
SURV    09   11   2    1P03M40M41M42
SURV    09   11   3    2P02M39M38
SURV    21   11   1    1M33S02S03
SURV    21   11   2    1M44M41M42P03
SURV    21   11   3    2M43M38P02
SURV    30   11   1    1M23S02S03
SURV    30   11   2    1M50M28P03
SURV    30   11   3    2M29P02S04S05
SURV    30   11   4    2M26P05
SURV    30   11   5    3M53P04
END
AVAIL   09   11   1    1S02S03M32
AVAIL   09   11   2    1P03M40M41M42
AVAIL   09   11   3    2P02M39M38
AVAIL   21   11   1    1M33S02S03
AVAIL   21   11   2    1M44M41M42P03
AVAIL   21   11   3    2M43M38P02
AVAIL   30   11   1    1M23S02S03
AVAIL   30   11   2    1M50M28P03
AVAIL   30   11   3    2M29P02S04S05
AVAIL   30   11   4    2M26P05
AVAIL   30   11   5    3M53P04
END
SURV    02   17   1    1S02S03M34M38
SURV    02   17   2    1P03M37
SURV    02   17   3    2P02M36
SURV    10   17   1    1M35S02S03
SURV    10   17   2    1M44M41M42P03
SURV    10   17   3    2M43M38P02
SURV    18   17   1    1M21S02S03
SURV    18   17   2    1M27M28P03
SURV    18   17   3    2M25S04S05P02
SURV    18   17   4    2M26P05
SURV    18   17   5    3M53P04
SURV    36   17   1    1M24S02S03
SURV    36   17   2    1M52M28P03
SURV    36   17   3    2M51P02S04S05
SURV    36   17   4    2M26P05
SURV    36   17   5    3M53P04
END
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AVAIL   02   17    1    1S02S03M34M38
AVAIL   02   17    2    1P03M37
AVAIL   02   17    3    2P02M36
AVAIL   10   17    1    1M35S02S03
AVAIL   10   17    2    1M44M41M42P03
AVAIL   10   17    3    2M43M38P02
AVAIL   18   17    1    1M21S02S03
AVAIL   18   17    2    1M27M28P03
AVAIL   18   17    3    2M25S04S05P02
AVAIL   18   17    4    2M26P05
AVAIL   18   17    5    3M53P04
AVAIL   36   17    1    1M24S02S03
AVAIL   36   17    2    1M52M28P03
AVAIL   36   17    3    2M51P02S04S05
AVAIL   36   17    4    2M26P05
AVAIL   36   17    5    3M53P04
END
COSTG    1  40000.    0.0      0.0       0.0       0
COSTG    2  10000.    5000.    0.0       0.0       1
COSTG    3  20000.    1000.    0.0       20000.    2
COSTG    4  5000.     2500.    500.      4500.     2
COSTG    5  1000.     150.     350.      150.      2
COSTG    6  1000.     150.     350.      150.      2
COSTG    7  1000.     150.     350.      150.      2
COSTG    8  10000.    5000.    0.0       0.0       1
COSTG    9  20000.    1000.    0.0       20000.    8
COSTG   10  5000.     2500.    500.      4500.     8
COSTG   11  1000.     150.     350.      150.      8
COSTG   12  1000.     150.     350.      150.      8
COSTG   13  1000.     150.     350.      150.      8
COSTM   21  1200.     200.     200.      900.     11
COSTM   22  800.      100.     50.       600.     12
COSTM   23  3500.     300.     350.      1800.    12
COSTM   24  1200.     200.     200.      900.     13
COSTM   25  1200.     20.      50.       900.     11
COSTM   26  3500.     300.     350.      1800.    10
COSTM   27  7000.     400.     1000.     5500.    11
COSTM   28  45000.    500.     1000.     35000.    9
COSTM   29  1200.     20.      50.       900.     12
COSTM   31  3500.     300.     350.      1800.     7
COSTM   32  3500.     300.     350.      1800.     6
COSTM   33  3500.     300.     350.      1800.     7
COSTM   34  1200.     200.      200.      900.     5
COSTM   35  1200.     200.      200.      900.     7
COSTM   36  1200.     20.       50.       900.     5
COSTM   37  1800.     20.       50.       1000.    5
COSTM   38  3000.     5000.     400.      2000.    4
COSTM   39  1200.     20.       50.       900.     6
COSTM   40  4500.     400.      900.      3800.    6
COSTM   41  0.        12000.    0.        0.       3
COSTM   42  40000.    400.      1000.     35000.   3
COSTM   43  1200.     20.       50.       900.     7
COSTM   44  4500.     400.      900.      3800.    7
COSTM   50  7000.     400.      1000.     5500.   12
COSTM   51  1200.     20.       50.       900.    13
COSTM   52  7000.     400.      1000.     5500.   13
COSTM   53  3000.     5000.     400.      2000.   13
END
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CANDIDATE 2.1 RESULTS

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DESIGN TYPE = F SYSTEM DUR. =    1.00 NO. OF MONTHS =    60 FLOW SCALING FACTORS =   1.0  5.0  2.0   .5   .3

 STA. NO.      STA. I.D.       SEG. NO.     SEG. ASSOCIATION


     1          3091500            5        1 2 3 4 5-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
     2          3094000            7        6 7 8 910-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
     3          3098000           25      212223242526-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
     4          3099500           29      2728293031-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
     5          3103500           13      1314151617181920-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
     6          3105500           33      323334-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
     7          3107500           36      35363738-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
     8          3095500           11      1112-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
PARAMETER NUMBER =   5
REACH NO. IMPL.   MN. PLCY.   CT      DELTA   IMPL. LOC.   EPSI     SEPSI    TUP     TDOWN


     1     F          F    1500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
     2     F          F    1500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
     3     F          F    1500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
     4     F          F    1500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
     5     F          F    1500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
     6     F          F    1500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
     7     F          F    1500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
     8     F          F    1500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
     9     F          F    1500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    10     F          F    1500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    11     F          F    1500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    12     F          F    1500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    13     F          F     500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    14     F          F     500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    15     F          F     500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    16     F          F     500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    17     F          F     500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    18     F          F     500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    19     F          F     500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    20     F          F     500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    21     F          F    1500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    22     F          F    1500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    23     F          F    1500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    24     F          F    1500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    25     F          F    1500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    26     F          F    1500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    27     F          F    1500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
    28     F          F    1500.000  -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
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        29    F          F   1500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        30    T          T    500.000     .04     12.50     15.000   60.000    6.75     .25
        31    F          F    500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        32    F          F    500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        33    F          F    500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        34    F          F    500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        35    F          F    500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        36    F          F    500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        37    F          F    500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        38    F          F    500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00

PARAMETER NUMBER =  10

REACH NO. IMPL.    MN. PLCY.   CT      DELTA   IMPL. LOC.   EPSI     SEPSI    TUP     TDOWN


         1    F          F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
         2    F          F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
         3    F          F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
         4    F          F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
         5    F          F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
         6    F          F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
         7    F          F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
         8    F          F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
         9    F          F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        10    F          F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        11    F          F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        12    F          F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        13    F          F      0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        14    F          F      0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        15    F          F      0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        16    F          F      0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        17    F          F      0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        18    F          F      0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        19    F          F      0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        20    F          F      0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        21    T          T       .005     .04     31.00       .020     .150    6.75     .25
        22    F          F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        23    F          F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        24    F          F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        25    F          F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        26    F          F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        27    F          F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        28    F          F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        29    F          F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        30    F          F      0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        31    F          F      0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
        32    F          F      0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
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   33     F        F      0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   34     F        F      0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   35     F        F      0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   36     F        F      0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   37     F        F      0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   38     F        F      0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00

PARAMETER NUMBER =  11
REACH NO. IMPL.   MN. PLCY.   CT     DELTA   IMPL. LOC.   EPSI     SEPSI    TUP     TDOWN


    1     F        F       .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    2     F        F       .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    3     F        F       .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    4     F        F       .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    5     F        F       .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    6     F        F       .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    7     F        F       .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    8     F        F       .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    9     T        T       .100     .04     37.00       .001     .005    6.75     .25
   10     F        F       .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   11     F        F       .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   12     F        F       .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   13     F        F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   14     F        F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   15     F        F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   16     F        F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   17     F        F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   18     F        F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   19     F        F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   20     F        F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   21     T        T       .100     .04     31.00       .001     .005    6.75     .25
   22     F        F       .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   23     F        F       .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   24     F        F       .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   25     F        F       .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   26     F        F       .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   27     F        F       .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   28     F        F       .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   29     F        F       .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   30     T        T       .005     .04     12.50       .001     .005    6.75     .25
   31     F        F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   32     F        F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   33     F        F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   34     F        F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   35     F        F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   36     F        F       .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
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     37      F          F          .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     38      F          F          .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00

PARAMETER NUMBER =  17
REACH NO. IMPL.    MN. PLCY.   CT      DELTA    IMPL. LOC.    EPSI     SEPSI     TUP     TDOWN


      1      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      2      T          T         5.000     .04     82.50        .050     .150    6.75     .25
      3      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      4      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      5      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      6      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      7      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      8      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
      9      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     10      T          T         5.000     .04     31.00        .050     .150    6.75     .25
     11      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     12      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     13      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     14      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     15      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     16      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     17      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     18      T          T         5.000     .04     36.80        .050     .150    6.75     .25
     19      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     20      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     21      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     22      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     23      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     24      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     25      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     26      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     27      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     28      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     29      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     30      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     31      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     32      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     33      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     34      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     35      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     36      T          T         5.000     .04      7.80        .050     .150    6.75     .25
     37      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     38      F          F         5.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
```

```
                    STATE 1 = OPERATING, STATE 2 = STAND-BY

MEANS NO..    MTTFS-1     MTTFS-2     MTTFA-1     MTTFA-2    MTTRA-1     MTTRA-2


    21          .20         .01         5.00      365.00      100.00      365.00
    22          .20         .01         5.00      365.00      100.00      365.00
    23          .20         .01         6.00      365.00      100.00      365.00
    24          .20         .01         5.00      365.00      100.00      365.00
    25          .20         .01         3.00         .30      100.00       45.00
    26          .01         .01         2.00         .50      365.00      365.00
    27          .20         .01         5.00        1.00      137.00      137.00
    28          .01         .01         3.00        3.00      365.00      365.00
    29          .20         .01         3.00         .30      100.00       45.00
    31          .20         .01         6.00      365.00      100.00      365.00
    32          .20         .01         6.00      365.00      100.00      365.00
    33          .20         .01         6.00      365.00      100.00      365.00
    34          .20         .01         5.00      365.00      100.00      365.00
    35          .20         .01         5.00      365.00      100.00      365.00
    36          .20         .01         3.00         .30      100.00       45.00
    37          .20         .01         3.00         .30      100.00       45.00
    38          .01         .01         2.00         .50      365.00      365.00
    39          .20         .01         3.00         .30      100.00       45.00
    40          .20         .01         5.00        1.00      137.00      137.00
    41          .01         .01        52.00       52.00     9999.00     9999.00
    42          .01         .01         3.00        3.00      365.00      365.00
    43          .20         .01         3.00         .30      100.00       45.00
    44          .20         .01         5.00        1.00      137.00      137.00
    50          .20         .01         5.00        1.00      137.00      137.00
    51          .20         .01         3.00         .30      100.00       45.00
    52          .20         .01         5.00        1.00      137.00      137.00
    53          .01         .01         2.00         .50      365.00      365.00



       PARAMETER NUMBER =  5 ELEMENT DESIGN FOR SURVIVABILITY

       REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN


          30         1            1        M22S 2S 3 -0 -0 -0 -0 -0 -0 -0
          30         2            1        M50M28P 3 -0 -0 -0 -0 -0 -0 -0
          30         3            2        M29P 2S 4S 5 -0 -0 -0 -0 -0 -0
          30         4            2        M26P 5 -0 -0 -0 -0 -0 -0 -0 -0
          30         5            3        M53P 4 -0 -0 -0 -0 -0 -0 -0 -0
        PARAMETER NUMBER =   5 ELEMENT DESIGN FOR AVAILABILITY

        REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN


           30         1            1        M22S 2S 3 -0 -0 -0 -0 -0 -0 -0
           30         2            1        M50M28P 3 -0 -0 -0 -0 -0 -0 -0
           30         3            2        M29P 2S 4S 5 -0 -0 -0 -0 -0 -0
           30         4            2        M26P 5 -0 -0 -0 -0 -0 -0 -0 -0
           30         5            3        M53P 4 -0 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                 LUDATF     2
*** I M S L(UERTST) ***  WARNING                 LEQT1F     2

PARAMETER NUMBER =   5

REACH NO. =  30 CAP =   7.63925E-03 SURV =   9.80935E-01 AVAIL =   9.99296E-01 ELEMENT EFF. =   7.48834E-03



       PARAMETER NUMBER = 10 ELEMENT DESIGN FOR SURVIVABILITY

       REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN


          21         1            1        M31S 2S 3 -0 -0 -0 -0 -0 -0 -0
          21         2            1        M44M41M42P 3 -0 -0 -0 -0 -0 -0
          21         3            2        M43M38P 2 -0 -0 -0 -0 -0 -0 -0
       PAHAMETER NUMBER =  10 ELEMENT DESIGN FOR AVAILABILITY

       REACH NO.  PATH NO.   NOHMAL STATUS  ELEMENT DESIGN

            21          1              1         M31S 2S 3 -0 -0 -0 -0 -0 -0 -0
            21          2              1         M44M41M42P 3 -0 -0 -0 -0 -0 -0
            21          3              2         M43M38P 2 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                    LUDATF      2
*** I M S L(UERTST) ***  WARNING                    LEQT1F      2

PARAMETER NUMBER =  10

REACH NO. =  21 CAP =   3.36824E-02 SURV =   9.80095E-01 AVAIL =   9.78445E-01 ELEMENT EFF. =   3.23004E-02



       PARAMETER NUMBER = 11 ELEMENT UESIGN FOR SURVIVABILITY

       REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

             9          1              1         S 2S 3M32 -0 -0 -0 -0 -0 -0 -0
             9          2              1         P 3M40M41M42 -0 -0 -0 -0 -0 -0
             9          3              2         P 2M39M38 -0 -0 -0 -0 -0 -0 -0
            21          1              1         M33S 2S 3 -0 -0 -0 -0 -0 -0 -0
            21          2              1         M44M41M42P 3 -0 -0 -0 -0 -0 -0
            21          3              2         M43M38P 2 -0 -0 -0 -0 -0 -0 -0
            30          1              1         M23S 2S 3 -0 -0 -0 -0 -0 -0 -0
            30          2              1         M50M28P 3 -0 -0 -0 -0 -0 -0 -0
            30          3              2         M29P 2S 4S 5 -0 -0 -0 -0 -0 -0
            30          4              2         M26P 5 -0 -0 -0 -0 -0 -0 -0
            30          5              3         M53P 4 -0 -0 -0 -0 -0 -0 -0
       PAHAMETER NUMBEH =  11 ELEMENT DESIGN FOR AVAILABILITY

       REACH NO.  PATH NO.   NOHMAL STATUS  ELEMENT DESIGN

             9          1              1         S 2S 3M32 -0 -0 -0 -0 -0 -0 -0
             9          2              1         P 3M40M41M42 -0 -0 -0 -0 -0 -0
             9          3              2         P 2M39M38 -0 -0 -0 -0 -0 -0 -0
            21          1              1         M33S 2S 3 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                    LUDATF      2
*** I M S L(UERTST) ***  WARNING                    LEQT1F      2
            21          2              1         M44M41M42P 3 -0 -0 -0 -0 -0 -0
            21          3              2         M43M38P 2 -0 -0 -0 -0 -0 -0 -0
            30          1              1         M23S 2S 3 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                    LUDATF      2
*** I M S L(UERTST) ***  WARNING                    LEQT1F      2
            30          2              1         M50M28P 3 -0 -0 -0 -0 -0 -0 -0
            30          3              2         M29P 2S 4S 5 -0 -0 -0 -0 -0 -0
            30          4              2         M26P 5 -0 -0 -0 -0 -0 -0 -0
            30          5              3         M53P 4 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                    LUDATF      2
*** I M S L(UERTST) ***  WARNING                    LEQT1F      2

PARAMETER NIMRFR =  11

REACH NO. =   9 CAP =   3.62958E-02 SURV =   9.80095E-01 AVAIL =   9.78445E-01 ELEMENT EFF. =   3.48066E-02

REACH NO. =  21 CAP =   1.02833E-02 SURV =   9.80095E-01 AVAIL =   9.78445E-01 ELEMENT EFF. =   9.86135E-03

REACH NO. =  30 CAP =   8.73741E-03 SURV =   9.80935E-01 AVAIL =   9.99296E-01 ELEMENT EFF. =   8.56480E-03
```

```
PARAMETER NUMBER = 17 ELEMENT DESIGN FOR SURVIVABILITY

REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

      2         1            1        S 2S 3M34M38 -0 -0 -0 -0 -0 -0
      2         2            1        P 3M37 -0 -0 -0 -0 -0 -0 -0 -0
      2         3            2        P 2M36 -0 -0 -0 -0 -0 -0 -0 -0
     10         1            1        M35S 2S 3 -0 -0 -0 -0 -0 -0 -0
     10         2            1        M44M41M42P 3 -0 -0 -0 -0 -0 -0
     10         3            2        M43M38P 2 -0 -0 -0 -0 -0 -0 -0
     18         1            1        M21S 2S 3 -0 -0 -0 -0 -0 -0 -0
     18         2            1        M27M28P 3 -0 -0 -0 -0 -0 -0 -0
     18         3            2        M25S 4S 5P 2 -0 -0 -0 -0 -0 -0
     18         4            2        M26P 5 -0 -0 -0 -0 -0 -0 -0 -0
     18         5            3        M53P 4 -0 -0 -0 -0 -0 -0 -0 -0
     36         1            1        M24S.2S 3 -0 -0 -0 -0 -0 -0 -0
     36         2            1        M52M28P 3 -0 -0 -0 -0 -0 -0 -0
     36         3            2        M51P 2S 4S 5 -0 -0 -0 -0 -0 -0
     36         4            2        M26P 5 -0 -0 -0 -0 -0 -0 -0 -0
     36         5            3        M53P 4 -0 -0 -0 -0 -0 -0 -0 -0
 PARAMETER NUMBER =  17 ELEMENT DESIGN FOR AVAILABILITY

 REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

            2         1           1        S 2S 3M34M38 -0 -0 -0 -0 -0 -0
            2         2           1        P 3M37 -0 -0 -0 -0 -0 -0 -0 -0
            2         3           2        P 2M36 -0 -0 -0 -0 -0 -0 -0 -0
           10         1           1        M35S 2S 3 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING              LUDATF    2
*** I M S L(UERTST) ***  WARNING              LEQT1F    2
           10         2           1        M44M41M42P 3 -0 -0 -0 -0 -0 -0
           10         3           2        M43M38P 2 -0 -0 -0 -0 -0 -0 -0
           18         1           1        M21S 2S 3 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING              LUDATF    2
*** I M S L(UERTST) ***  WARNING              LEQT1F    2
           18         2           1        M27M28P 3 -0 -0 -0 -0 -0 -0 -0
           18         3           2        M25S 4S 5P 2 -0 -0 -0 -0 -0 -0
           18         4           2        M26P 5 -0 -0 -0 -0 -0 -0 -0 -0
           18         5           3        M53P 4 -0 -0 -0 -0 -0 -0 -0 -0
           36         1           1        M24S 2S 3 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING              LUDATF    2
*** I M S L(UERTST) ***  WARNING              LEQT1F    2
           36         2           1        M52M28P 3 -0 -0 -0 -0 -0 -0 -0
           36         3           2        M51P 2S 4S 5 -0 -0 -0 -0 -0 -0
           36         4           2        M26P 5 -0 -0 -0 -0 -0 -0 -0 -0
           36         5           3        M53P 4 -0 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING              LUDATF    2
*** I M S L(UERTST) ***  WARNING              LEQT1F    2

PARAMETER NUMBER =  17

REACH NO. =   2 CAP =   9.23774E-03 SURV =   7.95719E-01 AVAIL =   9.46683E-01 ELEMENT EFF. =   6.95873E-03

REACH NO. =  10 CAP =   2.16616E-03 SURV =   9.80095E-01 AVAIL =   9.78261E-01 ELEMENT EFF. =   2.07689E-03

REACH NO. =  18 CAP =   3.14209E-02 SURV =   9.80935E-01 AVAIL =   9.99296E-01 ELEMENT EFF. =   3.08001E-02

REACH NO. =  36 CAP =   3.03844E-02 SURV =   9.80935E-01 AVAIL =   9.99296E-01 ELEMENT EFF. =   2.97842E-02


  SYSTEM EFFECTIVENESS =   2.95857E-01

 TOTAL COST =   2.00490E+05

 COST/EFF. =   6.77657E+05
```

CANDIDATE 1.2 DATA DECK

```
CONTROL F 001020011221011120     5.     60  1.   5.   2.   .5  .25     T
USGS     01   03091500 05 0102030405
USGS     02   03094000 07 0607080910
USGS     03   03098000 25 212223242526
USGS     04   03099500 29 2728293031
USGS     05   03103500 13 1314151617181920
USGS     06   03105500 33 323334
USGS     07   03107500 36 35363738
USGS     08   03095500 11 1112
END
```

"RIBAM SDD"

```
CHAR0501          1500.
CHAR0502          1500.
CHAR0503          1500.
CHAR0504          1500.
CHAR0505          1500.
CHAR0506          1500.
CHAR0507          1500.
CHAR0508          1500.
CHAR0509          1500.
CHAR0510          1500.
CHAR0511          1500.
CHAR0512          1500.
CHAR0513           500.
CHAR0514           500.
CHAR0515           500.
CHAR0516           500.
CHAR0517           500.
CHAR0518           500.
CHAR0519           500.
CHAR0520           500.
CHAR0521          1500.
CHAR0522          1500.
CHAR0523          1500.
CHAR0524          1500.
CHAR0525          1500.
CHAR0526          1500.
CHAR0527          1500.
CHAR0528          1500.
CHAR0529          1500.
CHAR0530TT         500.        3.5       11.0       15.0       15.0       365.       0.
CHAR0531           500.
CHAR0532           500.
CHAR0533           500.
CHAR0534           500.
CHAR0535           500.
CHAR0536           500.
CHAR0537           500.
CHAR0538           500.
END
CHAR1001           .005
CHAR1002           .005
CHAR1003           .005
CHAR1004           .005
CHAR1005           .005
CHAR1006           .005
CHAR1007           .005
CHAR1008           .005
CHAR1009           .005
CHAR1010           .005
CHAR1011           .005
CHAR1012           .005
```

```
CHAR1013         .0
CHAR1014         .0
CHAR1015         .0
CHAR1016         .0
CHAR1017         .0
CHAR1018         .0
CHAR1019         .0
CHAR1020         .0
CHAR1021TT      .005      3.5      30.6      0.05      0.10      365.      0.
CHAR1022         .005
CHAR1023         .005
CHAR1024         .005
CHAR1025         .005
CHAR1026         .005
CHAR1027         .005
CHAR1028         .005
CHAR1029         .005
CHAR1030         .0
CHAR1031         .0
CHAR1032        0.00
CHAR1033        0.0
CHAR1034        0.0
CHAR1035        0.00
CHAR1036        0.0
CHAR1037        0.0
CHAR1038        0.0
END
CHAR1101           0.1
CHAR1102           0.1
CHAR1103           0.1
CHAR1104           0.1
CHAR1105           0.1
CHAR1106           0.1
CHAR1107           0.1
CHAR1108           0.1
CHAR1109TT        0.1      7.       37.0      .001      .002      365.      0.
CHAR1110           0.1
CHAR1111           0.1
CHAR1112           0.1
CHAR1113         0.005
CHAR1114         0.005
CHAR1115         0.005
CHAR1116         0.005
CHAR1117         0.005
CHAR1118         0.005
CHAR1119         0.005
CHAR1120         0.005
CHAR1121          0.1      7.0      30.6      0.001     0.002     365.      0.
CHAR1122           0.1
CHAR1123           0.1
CHAR1124           0.1
CHAR1125           0.1
CHAR1126           0.1
CHAR1127           0.1
CHAR1128           0.1
CHAR1129           0.1
CHAR1130TT       0.005     3.5      11.0      0.001     0.002     365.      0.
CHAR1131         0.005
CHAR1132         0.005
CHAR1133         0.005
CHAR1134         0.005
CHAR1135         0.005
CHAR1136         0.005
CHAR1137         0.005
CHAR1138       0.005
END
```

```
CHAR1701          5.0
CHAR1702TT       5.0      90.       82.5       0.02       0.10       365.      0.
CHAR1703          5.0
CHAR1704          5.0
CHAR1705          5.0
CHAR1706          5.0
CHAR1707          5.0
CHAR1708          5.0
CHAR1709          5.0
CHAR1710          5.0
CHAR1711          5.0
CHAR1712          5.0
CHAR1713          5.0
CHAR1714          5.0
CHAR1715          5.0
CHAR1716          5.0
CHAR1717          5.0
CHAR1718TT       5.0      7.        36.8       0.02       0.10       365.       0.
CHAR1719          5.0
CHAR1720          5.0
CHAR1721TT       5.0      3.5       30.6      0.02       0.10       365.      0.
CHAR1722          5.0
CHAR1723          5.0
CHAR1724          5.0
CHAR1725          5.0
CHAR1726          5.0
CHAR1727          5.0
CHAR1728          5.0
CHAR1729          5.0
CHAR1730          5.0
CHAR1731          5.0
CHAR1732          5.0
CHAR1733          5.0
CHAR1734          5.0
CHAR1735          5.0
CHAR1736TT        5.0      7.0       4.0       0.02       0.10        365.      0.
CHAR1737          5.0
CHAR1738          5.0
END
MTTF     01       0.2       0.01       2.0        1.0       365.       365.
MTTF     02      0.01       0.01       2.0       0.01       365.       365.
MTTF     03      0.01       0.01       2.0       0.01       365.       365.
MTTF     04       0.2       0.01       4.0        2.0       365.       365.
MTTF     05      0.02       0.02       4.0        0.1        52.        52.
MTTF     06       0.2       0.01       2.0        1.0       365.       365.
MTTF     07      0.01       0.01       2.0       0.01       365.       365.
MTTF     08      0.01       0.01       2.0       0.01       365.       365.
MTTF     09       0.2       0.01       4.0        2.0       365.       365.
MTTF     10       0.2       0.01       2.0        1.0       365.       365.
MTTF     11      0.01       0.01       2.0       0.01       365.       365.
MTTF     12       0.2       0.01       4.0        2.0       365.       365.
MTTF     13       0.2       0.01       4.0        2.0       365.       365.
MTTF     14      0.02       0.02       4.0        0.1        52.        52.
MTTF     15       0.2       0.01       2.0        1.0       365.       365.
MTTF     16      0.01       0.01       2.0        .01       365.       365.
MTTF     17       0.2       0.01       4.0        2.0       365.       365.
MTTF     18       0.2       0.01       4.0        2.0       365.       365.
MTTF     19       0.2        0.1       4.0        1.0       122.       122.
END
```

```
SURV    30    05     1     1S02S03
SURV    30    05     2     1M10M13P03
SURV    30    05     3     2M15M18P02
END
AVAIL   30    05     1     1S02S03
AVAIL   30    05     2     1M10M13P03
AVAIL   30    05     3     2M15M18P02
END
SURV    21    10     1     1S02S03
SURV    21    10     2     1M01M02P03
SURV    21    10     3     2M06M07P02
END
AVAIL   21    10     1     1S02S03
AVAIL   21    10     2     1M01M02P03
AVAIL   21    10     3     2M06M07P02
END
SURV    09    11     1     1M05S02S03
SURV    09    11     2     1M01M03P03
SURV    09    11     3     2M06M08P02
SURV    21    11     1     1S02S03M05
SURV    21    11     2     1M01M03P03
SURV    21    11     3     2M06M08P02
SURV    30    11     1     1M14S02S03
SURV    30    11     2     1M10M11P03
SURV    30    11     3     2M15M16P02
END
AVAIL   09    11     1     1M05S02S03
AVAIL   09    11     2     1M01M03P03
AVAIL   09    11     3     2M06M08P02
AVAIL   21    11     1     1S02S03M05
AVAIL   21    11     2     1M01M03P03
AVAIL   21    11     3     2M06M08P02
AVAIL   30    11     1     1M14S02S03
AVAIL   30    11     2     1M10M11P03
AVAIL   30    11     3     2M15M16P02
END
SURV    02    17     1     1S02S03M19
SURV    02    17     2     1M01M04P03
SURV    02    17     3     2M06M09P02
SURV    18    17     1     1S02S03
SURV    18    17     2     1M10M12P03
SURV    18    17     3     2M15M17P02
SURV    21    17     1     1S02S03
SURV    21    17     2     1M01M04P03
SURV    21    17     3     2M06M09P02
SURV    36    17     1     1S02S03
SURV    36    17     2     1M10M12P03
SURV    36    17     3     2M15M17P02
END
AVAIL   02    17     1     1S02S03M19
AVAIL   02    17     2     1M01M04P03
AVAIL   02    17     3     2M06M09P02
AVAIL   18    17     1     1S02S03
AVAIL   18    17     2     1M10M12P03
AVAIL   18    17     3     2M15M17P02
AVAIL   21    17     1     1S02S03
AVAIL   21    17     2     1M01M04P03
AVAIL   21    17     3     2M06M09P02
AVAIL   36    17     1     1S02S03
AVAIL   36    17     2     1M10M12P03
AVAIL   36    17     3     2M15M17P02
END
COSTG    1     40000.        0.         0.         0.    0
COSTG    2     10000.  20000.           0.         0.    1
COSTG    3     20000.  22500.    5000.     10000.        2
COSTG    4      5000.  12500.    2500.      1000.        2
COSTG    5     10000.  25000.             0.           0.    1
COSTG    6     20000.  22500.    5000.      10000.           5
COSTG    7      5000.  7500.     1250.      1000.            5
COSTG    8      5000.  7500.     1250.      1000.            5
COSTM    1   5200.     50000.    3000.      1500.            4
COSTM    2       400.  5000.     0.         0.               4
COSTM    3       400.  2000.              0.           0.    4
COSTM    4       600.  100.      1000.      50.              4
COSTM    5      1500.  250.               0.        1500.    3
COSTM    6      3000.  5000.     2000.      500.             4
COSTM    7       400.  250.               0.           0.    4
COSTM    8       400.  250.               0.           0.    4
COSTM    9       600.  25.       250.       0.               4
COSTM   10   5200.     35000.    2000.      1500.            7
COSTM   11       400.  5000.      0.        0.               7
COSTM   12       600.  50.       500.       50.              7
COSTM   13       300.  100.      500.       50.              7
COSTM   14      1500.  250.               0.        1500.    6
COSTM   15   5200.     35000.    2000.      1500.            8
COSTM   16       400.  250.               0.           0.    8
COSTM   17       600.  50.       500.       50.              8
COSTM   18       300.  50.       250.       50.              8
COSTM   19      1500.  1000.     500.       200.             4
END
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CANDIDATE 1.2 RESULTS

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DESIGN TYPE = F SYSTEM DUR. =    5.00 NO. OF MONTHS =    60 FLOW SCALING FACTORS =   1.0  5.0  2.0   .5   .3


 STA. NO.      STA. I.D.       SEG. NO.     SEG. ASSOCIATION



     1           3041500           5       1 2 3 4 5-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

     2           3094000           7       6 7 8 910-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

     3           3098000          25      212223242526-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

     4           3099500          29      2728293031-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

     5           3103500          13      1314151617181920-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

     6           3105500          33      323334-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

     7           3107500          36      35363738-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

     8           3095500          11      1112-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

PARAMETER NUMBER =   5

REACH NO. IMPL.   MN. PLCY.   CT      DFLTA   IMPL. LOC.   EPSI      SEPSI     TUP      TDOWN


     1      F          F     1500.000   -0.00      -0.00      -0.000    -0.000    -0.00    -0.00

     2      F          F     1500.000   -0.00      -0.00      -0.000    -0.000    -0.00    -0.00

     3      F          F     1500.000   -0.00      -0.00      -0.000    -0.000    -0.00    -0.00

     4      F          F     1500.000   -0.00      -0.00      -0.000    -0.000    -0.00    -0.00

     5      F          F     1500.000   -0.00      -0.00      -0.000    -0.000    -0.00    -0.00

     6      F          F     1500.000   -0.00      -0.00      -0.000    -0.000    -0.00    -0.00

     7      F          F     1500.000   -0.00      -0.00      -0.000    -0.000    -0.00    -0.00

     8      F          F     1500.000   -0.00      -0.00      -0.000    -0.000    -0.00    -0.00

     9      F          F     1500.000   -0.00      -0.00      -0.000    -0.000    -0.00    -0.00

    10      F          F     1500.000   -0.00      -0.00      -0.000    -0.000    -0.00    -0.00

    11      F          F     1500.000   -0.00      -0.00      -0.000    -0.000    -0.00    -0.00
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     12    F        F    1500.000  -0.00    -0.00     -0.000  -0.000  -0.00   -0.00
     13    F        F     500.000  -0.00    -0.00     -0.000  -0.000  -0.00   -0.00
     14    F        F     500.000  -0.00    -0.00     -0.000  -0.000  -0.00   -0.00
     15    F        F     500.000  -0.00    -0.00     -0.000  -0.000  -0.00   -0.00
     16    F        F     500.000  -0.00    -0.00     -0.000  -0.000  -0.00   -0.00
     17    F        F     500.000  -0.00    -0.00     -0.000  -0.000  -0.00   -0.00
     18    F        F     500.000  -0.00    -0.00     -0.000  -0.000  -0.00   -0.00
     19    F        F     500.000  -0.00    -0.00     -0.000  -0.000  -0.00   -0.00
     20    F        F     500.000  -0.00    -0.00     -0.000  -0.000  -0.00   -0.00
     21    F        F    1500.000  -0.00    -0.00     -0.000  -0.000  -0.00   -0.00
     22    F        F    1500.000  -0.00    -0.00     -0.000  -0.000  -0.00   -0.00
     23    F        F    1500.000  -0.00    -0.00     -0.000  -0.000  -0.00   -0.00
     24    F        F    1500.000  -0.00    -0.00     -0.000  -0.000  -0.00   -0.00
     25    F        F    1500.000  -0.00    -0.00     -0.000  -0.000  -0.00   -0.00
     26    F        F    1500.000  -0.00    -0.00     -0.000  -0.000  -0.00   -0.00
     27    F        F    1500.000  -0.00    -0.00     -0.000  -0.000  -0.00   -0.00
     28    F        F    1500.000  -0.00    -0.00     -0.000  -0.000  -0.00   -0.00
     29    F        F    1500.000  -0.00    -0.00     -0.000  -0.000  -0.00   -0.00
     30    T        T     500.000   3.50    11.00     15.000  15.000  365.00   0.00
     31    F        F     500.000  -0.00    -0.00     -0.000  -0.000  -0.00   -0.00
     32    F        F     500.000  -0.00    -0.00     -0.000  -0.000  -0.00   -0.00
     33    F        F     500.000  -0.00    -0.00     -0.000  -0.000  -0.00   -0.00
     34    F        F     500.000  -0.00    -0.00     -0.000  -0.000  -0.00   -0.00
     35    F        F     500.000  -0.00    -0.00     -0.000  -0.000  -0.00   -0.00
     36    F        F     500.000  -0.00    -0.00     -0.000  -0.000  -0.00   -0.00
     37    F        F     500.000  -0.00    -0.00     -0.000  -0.000  -0.00   -0.00
     38    F        F     500.000  -0.00    -0.00     -0.000  -0.000  -0.00   -0.00


PARAMETER NUMBER =  10
REACH NO. IMPL.   MN. PLCY.   CT     DELTA   IMPL. LOC.  EPSI     SEPSI    TUP    TDOWN


       1    F         F      .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
       2    F         F      .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
       3    F         F      .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
       4    F         F      .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
       5    F         F      .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
       6    F         F      .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
       7    F         F      .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
       8    F         F      .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
       9    F         F      .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
      10    F         F      .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
      11    F         F      .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
      12    F         F      .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
      13    F         F     0.000   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
      14    F         F     0.000   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
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   15     F          F       0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   16     F          F       0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   17     F          F       0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   18     F          F       0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   19     F          F       0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   20     F          F       0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   21     T          T        .005    7.50     30.00       .050     .100  365.00    0.00
   22     F          F        .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   23     F          F        .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   24     F          F        .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   25     F          F        .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   26     F          F        .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   27     F          F        .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   28     F          F        .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   29     F          F        .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   30     F          F       0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   31     F          F       0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   32     F          F       0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   33     F          F       0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   34     F          F       0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   35     F          F       0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   36     F          F       0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   37     F          F       0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   38     F          F       0.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
PARAMETER NUMBER =  11
REACH NO. IMPL.   MN. PLCY.   CT     DELTA   IMPL. LOC.   EPSI     SEPSI    TUP     TDOWN

    1     F          F        .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    2     F          F        .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    3     F          F        .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    4     F          F        .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    5     F          F        .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    6     F          F        .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    7     F          F        .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    8     F          F        .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    9     T          T        .100    7.00     37.00       .001     .002  365.00    0.00
   10     F          F        .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   11     F          F        .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   12     F          F        .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   13     F          F        .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   14     F          F        .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   15     F          F        .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   16     F          F        .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   17     F          F        .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   18     F          F        .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
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         19     F          F         .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         20     F          F         .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         21     F          F         .100    7.00      30.60        .001     .002  365.00    0.00
         22     F          F         .100   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         23     F          F         .100   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         24     F          F         .100   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         25     F          F         .100   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         26     F          F         .100   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         27     F          F         .100   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         28     F          F         .100   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         29     F          F         .100   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         30     T          T         .005    3.50      11.00        .001     .002  365.00    0.00
         31     F          F         .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         32     F          F         .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         33     F          F         .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         34     F          F         .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         35     F          F         .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         36     F          F         .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         37     F          F         .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         38     F          F         .005   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00

PARAMETER NUMBER =  17
REACH NO. IMPL.   MN. PLCY.   CT      DELTA   IMPL. LOC.   EPSI     SEPSI    TUP     TDOWN


          1     F          F        5.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
          2     T          T        5.000   90.00      82.50        .020     .100  365.00    0.00
          3     F          F        5.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
          4     F          F        5.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
          5     F          F        5.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
          6     F          F        5.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
          7     F          F        5.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
          8     F          F        5.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
          9     F          F        5.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         10     F          F        5.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         11     F          F        5.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         12     F          F        5.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         13     F          F        5.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         14     F          F        5.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         15     F          F        5.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         16     F          F        5.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         17     F          F        5.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         18     T          T        5.000    7.00      36.80        .020     .100  365.00    0.00
         19     F          F        5.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         20     F          F        5.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         21     T          T        5.000    3.50      30.60        .020     .100  365.00    0.00
         22     F          F        5.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
         23     F          F        5.000   -0.00      -0.00      -0.000   -0.000   -0.00   -0.00
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     24    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     25    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     26    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     27    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     28    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     29    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     30    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     31    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     32    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     33    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     34    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     35    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     36    T         T      5.000   7.00      4.00       .020    .100  365.00   0.00
     37    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00
     38    F         F      5.000  -0.00     -0.00     -0.000  -0.000  -0.00  -0.00


                       STATE 1 = OPERATING, STATE 2 = STAND-BY

MEANS NO..    MTTFS-1     MTTFS-2     MTTFA-1     MTTFA-2    MTTRA-1     MTTRA-2

     1          .20         .01        2.00        1.00      365.00      365.00
     2          .01         .01        2.00         .01      365.00      365.00
     3          .01         .01        2.00         .01      365.00      365.00
     4          .20         .01        4.00        2.00      365.00      365.00
     5          .02         .02        4.00         .10       52.00       52.00
     6          .20         .01        2.00        1.00      365.00      365.00
     7          .01         .01        2.00         .01      365.00      365.00
     8          .01         .01        2.00         .01      365.00      365.00
     9          .20         .01        4.00        2.00      365.00      365.00
    10          .20         .01        2.00        1.00      365.00      365.00
    11          .01         .01        2.00         .01      365.00      365.00
    12          .20         .01        4.00        2.00      365.00      365.00
    13          .20         .01        4.00        2.00      365.00      365.00
    14          .02         .02        4.00         .10       52.00       52.00
    15          .20         .01        2.00        1.00      365.00      365.00
    16          .01         .01        2.00         .01      365.00      365.00
    17          .20         .01        4.00        2.00      365.00      365.00
    18          .20         .01        4.00        2.00      365.00      365.00
    19          .20         .10        4.00        1.00      122.00      122.00



         PARAMETER NUMBER =  5 ELEMENT DESIGN FOR SURVIVABILITY

         REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

             30        1           1       S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
             30        2           1       M10M13P 3 -0 -0 -0 -0 -0 -0 -0
             30        3           2       M15M1AP 2 -0 -0 -0 -0 -0 -0 -0
         PARAMETER NUMBER =   5 ELEMENT DESIGN FOR AVAILABILITY

         REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

             30        1           1       S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
             30        2           1       M10M13P 3 -0 -0 -0 -0 -0 -0 -0
             30        3           2       M15M1AP 2 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                   LUDATF     2
*** I M S L(UERTST) ***  WARNING                   LEQTIF     2

PARAMETER NUMBER =   5

REACH NO. =  30 CAP =   5.55207E-03 SURV =   3.92912E-01 AVAIL =   9.99801E-01 ELEMENT EFF. =   2.10136E-03
```

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```
        PARAMETER NUMBER = 10 ELEMENT DESIGN FOR SURVIVABILITY

        REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

            21         1            1        S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
            21         2            1        M 1M 2P 3 -0 -0 -0 -0 -0 -0 -0
            21         3            2        M 6M 7P 2 -0 -0 -0 -0 -0 -0 -0
       PARAMETER NUMBER =  10 ELEMENT DESIGN FOR AVAILABILITY

       REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

           21         1            1        S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
           21         2            1        M 1M 2P 3 -0 -0 -0 -0 -0 -0 -0
           21         3            2        M 6M 7P 2 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                 LUDATF     2
*** I M S L(UERTST) ***  WARNING                 LEQT1F     2

PARAMETER NUMBER =  10

REACH NO. =  21 CAP =   2.53191E-02 SURV =   6.99599E-01 AVAIL =   9.99925E-01 ELEMENT EFF. =   1.77119E-02



       PARAMETER NUMBER = 11 ELEMENT DESIGN FOR SURVIVABILITY

       REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

            9         1            1        M 5S 2S 3 -0 -0 -0 -0 -0 -0 -0
            9         2            1        M 1M 3P 3 -0 -0 -0 -0 -0 -0 -0
            9         3            2        M 6M 8P 2 -0 -0 -0 -0 -0 -0 -0
           21         1            1        S 2S 3M 5 -0 -0 -0 -0 -0 -0 -0
           21         2            1        M 1M 3P 3 -0 -0 -0 -0 -0 -0 -0
           21         3            2        M 6M 8P 2 -0 -0 -0 -0 -0 -0 -0
           30         1            1        M14S 2S 3 -0 -0 -0 -0 -0 -0 -0
           30         2            1        M10M11P 3 -0 -0 -0 -0 -0 -0 -0
           30         3            2        M15M16P 2 -0 -0 -0 -0 -0 -0 -0
        PARAMETER NUMBER =  11 ELEMENT DESIGN FOR AVAILABILITY

        REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

            9         1            1        M 5S 2S 3 -0 -0 -0 -0 -0 -0 -0
            9         2            1        M 1M 3P 3 -0 -0 -0 -0 -0 -0 -0
            9         3            2        M 6M 8P 2 -0 -0 -0 -0 -0 -0 -0
           21         1            1        S 2S 3M 5 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                 LUDATF     2
*** I M S L(UERTST) ***  WARNING                 LEQT1F     2
           21         2            1        M 1M 3P 3 -0 -0 -0 -0 -0 -0 -0
           21         3            2        M 6M 8P 2 -0 -0 -0 -0 -0 -0 -0
           30         1            1        M14S 2S 3 -0 -0 -0 -0 -0 -0 -0
           30         2            1        M10M11P 3 -0 -0 -0 -0 -0 -0 -0
           30         3            2        M15M16P 2 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                 LUDATF     2
*** I M S L(UERTST) ***  WARNING                 LEQT1F     2

PARAMETER NUMBER =  11

REACH NO. =   9 CAP =   1.95188E-02 SURV =   6.33022E-01 AVAIL =   9.28502E-01 ELEMENT EFF. =   1.14724E-02

REACH NO. =  30 CAP =   6.99408E-03 SURV =   6.33022E-01 AVAIL =   9.28502E-01 ELEMENT EFF. =   4.11121E-03
```

```
PARAMETER NUMBER = 17 ELEMENT DESIGN FOR SURVIVABILITY

REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

      2         1            1        S 2S 3M19 -0 -0 -0 -0 -0 -0 -0
      2         2            1        M 1M 4P 3 -0 -0 -0 -0 -0 -0 -0
      2         3            2        M 6M 9P 2 -0 -0 -0 -0 -0 -0 -0
     18         1            1        S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
     18         2            1        M10M12P 3 -0 -0 -0 -0 -0 -0 -0
     18         3            2        M15M17P 2 -0 -0 -0 -0 -0 -0 -0
     21         1            1        S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
     21         2            1        M 1M 4P 3 -0 -0 -0 -0 -0 -0 -0
     21         3            2        M 6M 9P 2 -0 -0 -0 -0 -0 -0 -0
     36         1            1        S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
     36         2            1        M10M12P 3 -0 -0 -0 -0 -0 -0 -0
     36         3            2        M15M17P 2 -0 -0 -0 -0 -0 -0 -0
PARAMETER NUMBER =  17 ELEMENT DESIGN FOR AVAILABILITY

REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

      2         1            1        S 2S 3M19 -0 -0 -0 -0 -0 -0 -0
      2         2            1        M 1M 4P 3 -0 -0 -0 -0 -0 -0 -0
      2         3            2        M 6M 9P 2 -0 -0 -0 -0 -0 -0 -0
     18         1            1        S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING          LUDATF      2
*** I M S L(UERTST) ***  WARNING          LEQT1F      2
     18         2            1        M10M12P 3 -0 -0 -0 -0 -0 -0 -0
     18         3            2        M15M17P 2 -0 -0 -0 -0 -0 -0 -0
     21         1            1        S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING          LUDATF      2
*** I M S L(UERTST) ***  WARNING          LEQT1F      2
     21         2            1        M 1M 4P 3 -0 -0 -0 -0 -0 -0 -0
     21         3            2        M 6M 9P 2 -0 -0 -0 -0 -0 -0 -0
     36         1            1        S 2S 3 -0 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING          LUDATF      2
*** I M S L(UERTST) ***  WARNING          LEQT1F      2
     36         2            1        M10M12P 3 -0 -0 -0 -0 -0 -0 -0
     36         3            2        M15M17P 2 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING          LUDATF      2
*** I M S L(UERTST) ***  WARNING          LEQT1F      2

PARAMETER NUMBER =  17
REACH NO. =   2 CAP =  2.57711E-04 SURV =  1.44544E-01 AVAIL =  9.68061E-01 ELEMENT EFF. =  3.60609E-05

REACH NO. =  18 CAP =  1.71128E-02 SURV =  3.92912E-01 AVAIL =  9.99801E-01 ELEMENT EFF. =  6.72250E-03

REACH NO. =  21 CAP =  2.66354E-02 SURV =  3.92912E-01 AVAIL =  9.99801E-01 ELEMENT EFF. =  1.04633E-02

REACH NO. =  36 CAP =  1.74748E-02 SURV =  3.92912E-01 AVAIL =  9.99801E-01 ELEMENT EFF. =  6.86471E-03



SYSTEM EFFECTIVENESS =  1.08351E-01

TOTAL COST =  4.36675E+05

COST/EFF. =  4.03020E+06
```

CANDIDATE 2.2 DATA DECK

```
CONTROL F 001020011221011120    5.    60  1.   5.   2.   .5  .25    T
USGS    01  03091500 05 0102030405
USGS    02  03094000 07 0607080910
USGS    03  03098000 25 212223242526
USGS    04  03099500 29 2728293031
USGS    05  03103500 13 1314151617181920
USGS    06  03105500 33 323334
USGS    07  03107500 36 35363738
USGS    08  03095500 11 1112
END
```

"RIBAM SDD"

```
CHAR0501          1500.
CHAR0502          1500.
CHAR0503          1500.
CHAR0504          1500.
CHAR0505          1500.
CHAR0506          1500.
CHAR0507          1500.
CHAR0508          1500.
CHAR0509          1500.
CHAR0510          1500.
CHAR0511          1500.
CHAR0512          1500.
CHAR0513           500.
CHAR0514           500.
CHAR0515           500.
CHAR0516           500.
CHAR0517           500.
CHAR0518           500.
CHAR0519           500.
CHAR0520           500.
CHAR0521          1500.
CHAR0522          1500.
CHAR0523          1500.
CHAR0524          1500.
CHAR0525          1500.
CHAR0526          1500.
CHAR0527          1500.
CHAR0528          1500.
CHAR0529          1500.
CHAR0530TT    500.          0.0417        12.5        15.0        60.0        6.75     0.25
CHAR0531           500.
CHAR0532           500.
CHAR0533           500.
CHAR0534           500.
CHAR0535           500.
CHAR0536           500.
CHAR0537           500.
CHAR0538           500.
END
CHAR1001           .005
CHAR1002           .005
CHAR1003           .005
CHAR1004           .005
CHAR1005           .005
CHAR1006           .005
CHAR1007           .005
CHAR1008           .005
CHAR1009           .005
CHAR1010           .005
CHAR1011           .005
CHAR1012           .005
CHAR1013           .0
CHAR1014           .0
CHAR1015           .0
CHAR1016           .0
CHAR1017           .0
CHAR1018           .0
CHAR1019           .0
CHAR1020           .0
CHAR1021TT    .005          0.0417        31.0        0.02        0.15        6.75     0.25
CHAR1022           .005
CHAR1023           .005
CHAR1024           .005
CHAR1025           .005
CHAR1026           .005
```

```
CHAR1027        .005
CHAR1028        .005
CHAR1029        .005
CHAR1030        .0
CHAR1031        .0
CHAR1032       0.00
CHAR1033       0.0
CHAR1034       0.0
CHAR1035       0.00
CHAR1036       0.0
CHAR1037       0.0
CHAR1038       0.0
END
CHAR1101          0.1
CHAR1102          0.1
CHAR1103          0.1
CHAR1104          0.1
CHAR1105          0.1
CHAR1106          0.1
CHAR1107          0.1
CHAR1108          0.1
CHAR1109TT   0.1          0.0417     37.00      .001      .005      6.75    0.25
CHAR1110          0.1
CHAR1111          0.1
CHAR1112          0.1
CHAR1113        0.005
CHAR1114        0.005
CHAR1115        0.005
CHAR1116        0.005
CHAR1117        0.005
CHAR1118        0.005
CHAR1119        0.005
CHAR1120        0.005
CHAR1121TT   0.1          0.0417     31.0       .001      .005      6.75    0.25
CHAR1122          0.1
CHAR1123          0.1
CHAR1124          0.1
CHAR1125          0.1
CHAR1126          0.1
CHAR1127          0.1
CHAR1128          0.1
CHAR1129          0.1
CHAR1130TT  0.005         0.0417     12.5       .001      .005      6.75    0.25
CHAR1131        0.005
CHAR1132        0.005
CHAR1133        0.005
CHAR1134        0.005
CHAR1135        0.005
CHAR1136        0.005
CHAR1137        0.005
CHAR1138    0.005
END
CHAR1701          5.0
CHAR1702TT   5.0          0.0417     82.5       0.05      0.15      6.75    0.25
CHAR1703          5.0
CHAR1704          5.0
CHAR1705          5.0
CHAR1706          5.0
CHAR1707          5.0
CHAR1708          5.0
CHAR1709          5.0
```

```
CHAR1710TT   5.0        0.0417      31.0      0.05      0.15      6.75    0.25
CHAR1711         5.0
CHAR1712         5.0
CHAR1713         5.0
CHAR1714         5.0
CHAR1715         5.0
CHAR1716         5.0
CHAR1717         5.0
CHAR1718TT   5.0        0.0417      36.8      0.05      0.15      6.75    0.25
CHAR1719         5.0
CHAR1720         5.0
CHAR1721     5.0
CHAR1722         5.0
CHAR1723         5.0
CHAR1724         5.0
CHAR1725         5.0
CHAR1726         5.0
CHAR1727         5.0
CHAR1728         5.0
CHAR1729         5.0
CHAR1730         5.0
CHAR1731         5.0
CHAR1732         5.0
CHAR1733         5.0
CHAR1734         5.0
CHAR1735         5.0
CHAR1736TT   5.0        0.0417      7.8       0.05      0.15      6.75    0.25
CHAR1737         5.0
CHAR1738         5.0
END
MTTF    21  .2        .01        5.      365.       100.       365.
MTTF    22  .2        .01        5.      365.       100.       365.
MTTF    23  .2        .01        6.      365.       100.       365.
MTTF    24  .2        .01        5.      365.       100.       365.
MTTF    25  .2        .01        3.      .3         100.       45.
MTTF    26  .01       .01        2.      .5         365.       365.
MTTF    27  .2        .01        5.      1.         137.       137.
MTTF    28  .01       .01        3.      3.         365.       365.
MTTF    29  .2        .01        3.      .3         100.       45.
MTTF    31    .2      .01        6.      365.       100.       365.
MTTF    32    .2      .01        6.      365.       100.       365.
MTTF    33    .2      .01        6.      365.       100.       365.
MTTF    34    .2      .01        5.      365.       100.       365.
MTTF    35    .2      .01        5.      365.       100.       365.
MTTF    36    .2      .01        3.      .3         100.       45.
MTTF    37    .2      .01        3.      .3         100.       45.
MTTF    38    .01     .01        2.      .5         365.       365.
MTTF    39    .2      .01        3.      .3         100.       45.
MTTF    40    .2      .01        5.      1.         137.       137.
MTTF    41    .01     .01        52.     52.          9999.      9999.
MTTF    42    .01     .01        3.      3.         365.       365.
MTTF    43    .2      .01        3.      .3         100.       45.
MTTF    44    .2      .01        5.      1.         137.       137.
MTTF    50    .2      .01        5.      1.         137.       137.
MTTF    51    .2      .01        3.      .3         100.       45.
MTTF    52     .2     .01        5.       1.       137.       137.
MTTF    53     .01     .01       2.       .5       365.       365.
END
SURV    30   05    1   1M22S02S03
SURV    30   05    2   1M50M28P03
SURV    30   05    3   2M29P02S04S05
SURV    30   05    4   2M26P05
SURV    30   05    5   3M53P04
END
AVAIL   30   05    1   1M22S02S03
AVAIL   30   05    2   1M50M28P03
AVAIL   30   05   3   2M29P02S04S05
AVAIL   30   05   4   2M26P05
AVAIL   30   05   5   3M53P04
END
SURV    21   10   1   1M31S02S03
SURV    21   10   2   1M44M41M42P03
SURV    21   10   3   2M43M38P02
END
AVAIL   21   10   1   1M31S02S03
AVAIL   21   10   2   1M44M41M42P03
AVAIL   21   10   3   2M43M38P02
END
SURV    09   11   1   1S02S03M32
SURV    09   11   2   1P03M40M41M42
SURV    09   11   3   2P02M39M38
SURV    21   11   1   1M33S02S03
SURV    21   11   2   1M44M41M42P03
SURV    21   11   3   2M43M38P02
SURV    30   11   1   1M23S02S03
SURV    30   11   2   1M50M28P03
SURV    30   11   3   2M29P02S04S05
SURV    30   11   4   2M26P05
SURV    30   11   5   3M53P04
END
AVAIL   09   11   1   1S02S03M32
AVAIL   09   11   2   1P03M40M41M42
AVAIL   09   11   3   2P02M39M38
AVAIL   21   11   1   1M33S02S03
AVAIL   21   11   2   1M44M41M42P03
AVAIL   21   11   3   2M43M38P02
AVAIL   30   11   1   1M23S02S03
AVAIL   30   11   2   1M50M28P03
AVAIL   30   11   3   2M29P02S04S05
AVAIL   30   11   4   2M26P05
AVAIL   30   11   5   3M53P04
END
SURV    02   17   1   1S02S03M34M38
SURV    02   17   2   1P03M37
SURV    02   17   3   2P02M36
SURV    10   17   1   1M35S02S03
SURV    10   17   2   1M44M41M42P03
SURV    10   17   3   2M43M38P02
SURV    18   17   1   1M21S02S03
SURV    18   17   2   1M27M28P03
SURV    18   17   3   2M25S04S05P02
SURV    18   17   4   2M26P05
SURV    18   17   5   3M53P04
SURV    36   17   1   1M24S02S03
SURV    36   17   2   1M52M28P03
SURV    36   17   3   2M51P02S04S05
SURV    36   17   4   2M26P05
SURV    36   17   5   3M53P04
END
AVAIL   02   17   1   1S02S03M34M38
AVAIL   02   17   2   1P03M37
AVAIL   02   17   3   2P02M36
AVAIL   10   17   1   1M35S02S03
AVAIL   10   17   2   1M44M41M42P03
AVAIL   10   17   3   2M43M38P02
AVAIL   18   17   1   1M21S02S03
AVAIL   18   17   2   1M27M28P03
AVAIL   18   17   3   2M25S04S05P02
AVAIL   18   17   4   2M26P05
AVAIL   18   17   5   3M53P04
AVAIL   36   17   1   1M24S02S03
AVAIL   36   17   2   1M52M28P03
AVAIL   36   17    3    2M51P02S04S05
AVAIL   36   17    4    2M26P05
AVAIL   36   17    5    3M53P04
END
COSTG    1  40000.     0.0      0.0         0.0         0
COSTG    2  10000.     25000.   0.0         0.0         1
COSTG    3  20000.     5000.    0.0         10000.      2
COSTG    4  5000.      12500.    2500.      1000.       2
COSTG    5  1000.       750.     1750.      0.          2
COSTG    6  1000.       750.      1750.     0.          2
COSTG    7  1000.      750.       1750.     0.          2
COSTG    8  10000.      25000.   .0        0.0          1
COSTG    9  20000.      5000.   0.0         10000.      8
COSTG   10  5000.      12500.    2500.      1000.       8
COSTG   11  1000.      750.      1750.      0.          8
COSTG   12  1000.      750.      1750.      0.          8
COSTG   13  1000.       750.      1750.     0.          8
COSTM   21  1200.       1000.     1000.      500.      11
COSTM   22  800.        500.      250.      100.       12
COSTM   23  3500.       1500.     1750.      500.      12
COSTM   24  1200.       1000.     1000.     500.       13
COSTM   25  1200.       100.      250.      100.       11
COSTM   26   5200.      25000.    2000.      1500.     10
COSTM   27  7000.       2000.     5000.      1000.     11
COSTM   28  45000.      2500.     5000.     20000.      9
COSTM   29  1200.       100.      250.       100.      12
COSTM   31  3500.       1500.     1750.      500.       7
COSTM   32  3500.       1500.     1750.      500.       6
COSTM   33  3500.       1500.     1750.      500.       7
COSTM   34  1200.       1000.     1000.      500.       5
COSTM   35  1200.       1000.     1000.      500.       7
COSTM   36  1200.       100.      250.       100.       5
COSTM   37  1800.       100.      250.      100.        5
COSTM   38   5200.      25000.    2000.      1500.      4
COSTM   39  1200.       100.      250.       100.       6
COSTM   40  4500.       2000.     4500.     1000.       6
COSTM   41  0.         60000.    0.        0.           3
COSTM   42  40000.      2000.     5000.      20000.     3
COSTM   43  1200.       100.      250.       100.       7
COSTM   44  4500.       2000.     4500.      1000.      7
COSTM   50  7000.       2000.     5000.      1000.     12
COSTM   51  1200.      100.       250.      100.       13
COSTM   52  7000.       2000.     5000.     1000.      13
COSTM   53  3000.      25000.    2000.       500.      13
END
#
```

CANDIDATE 2.2 RESULTS

```
DESIGN TYPE = F SYSTEM DUR. =    5.00 NO. OF MONTHS =    60 FLOW SCALING FACTORS =   1.0  5.0  2.0   .5   .3


 STA. NO.      STA. I.D.      SEG. NO.     SEG. ASSOCIATION



    1           3091500           5        1 2 3 4 5-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
    2           3094000           7        6 7 8 910-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
    3           3098000          25       212223242526-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
    4           3099500          29       2728293031-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
    5           3103500          13       1314151617181920-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
    6           3105500          33       323334-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
    7           3107500          36       35363738-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
    8           3095500          11       1112-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
```

```
PARAMETER NUMBER =   5
REACH NO. IMPL.    MN. PLCY.   CT       DFLTA   IMPL. LOC.   EPSI      SEPSI     TUP      TDOWN


     1      F         F    1500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
     2      F         F    1500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
     3      F         F    1500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
     4      F         F    1500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
     5      F         F    1500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
     6      F         F    1500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
     7      F         F    1500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
     8      F         F    1500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
     9      F         F    1500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    10      F         F    1500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    11      F         F    1500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    12      F         F    1500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    13      F         F     500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    14      F         F     500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    15      F         F     500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    16      F         F     500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    17      F         F     500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    18      F         F     500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    19      F         F     500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    20      F         F     500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    21      F         F    1500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    22      F         F    1500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    23      F         F    1500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    24      F         F    1500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    25      F         F    1500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    26      F         F    1500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    27      F         F    1500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    28      F         F    1500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    29      F         F    1500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    30      T         T     500.000      .04     12.50     15.000    60.000     6.75      .25
    31      F         F     500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    32      F         F     500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    33      F         F     500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    34      F         F     500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    35      F         F     500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    36      F         F     500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    37      F         F     500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
    38      F         F     500.000    -0.00     -0.00     -0.000    -0.000    -0.00    -0.00
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PARAMETER NUMBER =  10
REACH NO. IMPL.    MN. PLCY.   CT     DELTA    IMPL. LOC.   EPSI     SEPSI    TUP     TDOWN


     1      F         F       .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     2      F         F       .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     3      F         F       .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     4      F         F       .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     5      F         F       .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     6      F         F       .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     7      F         F       .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     8      F         F       .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
     9      F         F       .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    10      F         F       .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    11      F         F       .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    12      F         F       .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    13      F         F      0.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    14      F         F      0.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    15      F         F      0.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    16      F         F      0.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    17      F         F      0.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    18      F         F      0.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    19      F         F      0.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    20      F         F      0.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    21      T         T       .005     .04     31.00        .020     .150    6.75     .25
    22      F         F       .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    23      F         F       .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    24      F         F       .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    25      F         F       .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    26      F         F       .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    27      F         F       .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    28      F         F       .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    29      F         F       .005   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    30      F         F      0.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    31      F         F      0.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    32      F         F      0.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    33      F         F      0.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    34      F         F      0.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    35      F         F      0.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    36      F         F      0.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    37      F         F      0.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
    38      F         F      0.000   -0.00     -0.00      -0.000   -0.000   -0.00   -0.00
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PARAMETER NUMBER =  11
REACH NO. IMPL.   MN. PLCY.   CT     DELTA   IMPL. LOC.   EPSI     SEPSI    TUP     TDOWN


     1     F         F       .100   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
     2     F         F       .100   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
     3     F         F       .100   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
     4     F         F       .100   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
     5     F         F       .100   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
     6     F         F       .100   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
     7     F         F       .100   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
     8     F         F       .100   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
     9     T         T       .100     .04     37.00      .001     .005    6.75     .25
    10     F         F       .100   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
    11     F         F       .100   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
    12     F         F       .100   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
    13     F         F       .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
    14     F         F       .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
    15     F         F       .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
    16     F         F       .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
    17     F         F       .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
    18     F         F       .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
    19     F         F       .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
    20     F         F       .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
    21     T         T       .100     .04     31.00      .001     .005    6.75     .25
    22     F         F       .100   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
    23     F         F       .100   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
    24     F         F       .100   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
    25     F         F       .100   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
    26     F         F       .100   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
    27     F         F       .100   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
    28     F         F       .100   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
    29     F         F       .100   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
    30     T         T       .005     .04     12.50      .001     .005    6.75     .25
    31     F         F       .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
    32     F         F       .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
    33     F         F       .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
    34     F         F       .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
    35     F         F       .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
    36     F         F       .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
    37     F         F       .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
    38     F         F       .005   -0.00     -0.00    -0.000   -0.000   -0.00   -0.00
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PARAMETER NUMBER =  17
REACH NO. IMPL.   MN. PLCY.   CT     DELTA   IMPL. LOC.   EPSI     SEPSI    TUP    TDOWN


    1      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    2      T          T      5.000     .04     82.50       .050     .150    6.75     .25
    3      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    4      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    5      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    6      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    7      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    8      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    9      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   10      T          T      5.000     .04     31.00       .050     .150    6.75     .25
   11      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   12      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   13      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   14      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   15      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   16      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   17      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   18      T          T      5.000     .04     36.80       .050     .150    6.75     .25
   19      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   20      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   21      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   22      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   23      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   24      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   25      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   26      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   27      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   28      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   29      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   30      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   31      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   32      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   33      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   34      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   35      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   36      T          T      5.000     .04      7.80       .050     .150    6.75     .25
   37      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   38      F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
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                        STATE 1 = OPERATING, STATE 2 = STAND-BY

MEANS NO..    MTTFS-1     MTTFS-2     MTTFA-1     MTTFA-2    MTTRA-1     MTTRA-2


    21          .20         .01        5.00       365.00      100.00      365.00
    22          .20         .01        5.00       365.00      100.00      365.00
    23          .20         .01        6.00       365.00      100.00      365.00
    24          .20         .01        5.00       365.00      100.00      365.00
    25          .20         .01        3.00          .30      100.00       45.00
    26          .01         .01        2.00          .50      365.00      365.00
    27          .20         .01        5.00         1.00      137.00      137.00
    28          .01         .01        3.00         3.00      365.00      365.00
    29          .20         .01        3.00          .30      100.00       45.00
    31          .20         .01        6.00       365.00      100.00      365.00
    32          .20         .01        6.00       365.00      100.00      365.00
    33          .20         .01        6.00       365.00      100.00      365.00
    34          .20         .01        5.00       365.00      100.00      365.00
    35          .20         .01        5.00       365.00      100.00      365.00
    36          .20         .01        3.00          .30      100.00       45.00
    37          .20         .01        3.00          .30      100.00       45.00
    38          .01         .01        2.00          .50      365.00      365.00
    39          .20         .01        3.00          .30      100.00       45.00
    40          .20         .01        5.00         1.00      137.00      137.00
    41          .01         .01       52.00        52.00     9999.00     9999.00
    42          .01         .01        3.00         3.00      365.00      365.00
    43          .20         .01        3.00          .30      100.00       45.00
    44          .20         .01        5.00         1.00      137.00      137.00
    50          .20         .01        5.00         1.00      137.00      137.00
    51          .20         .01        3.00          .30      100.00       45.00
    52          .20         .01        5.00         1.00      137.00      137.00
    53          .01         .01        2.00          .50      365.00      365.00




      PARAMETER NUMBER =  5 ELEMENT DESIGN FOR SURVIVABILITY

      REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN


          30         1            1        M22S 2S 3 -0 -0 -0 -0 -0 -0 -0
          30         2            1        M50M2AP 3 -0 -0 -0 -0 -0 -0 -0
          30         3            2        M29P 2S 4S 5 -0 -0 -0 -0 -0 -0
          30         4            2        M26P 5 -0 -0 -0 -0 -0 -0 -0 -0
          30         5            3        M53P 4 -0 -0 -0 -0 -0 -0 -0 -0

      PARAMETER NUMBER =   5 ELEMENT DESIGN FOR AVAILABILITY

      REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN


          30         1            1        M22S 2S 3 -0 -0 -0 -0 -0 -0 -0
          30         2            1        M50M2AP 3 -0 -0 -0 -0 -0 -0 -0
          30         3            2        M29P 2S 4S 5 -0 -0 -0 -0 -0 -0
          30         4            2        M26P 5 -0 -0 -0 -0 -0 -0 -0 -0
          30         5            3        M53P 4 -0 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                 LUDATF     2
*** I M S L(UERTST) ***  WARNING                 LEQTIF     2

PARAMETER NUMBER =   5

REACH NO. =  30 CAP =   7.63925E-03 SURV =   7.25916E-01 AVAIL =   9.99296E-01 ELEMENT EFF. =   5.54156E-03




      PARAMETER NUMBER = 10 ELEMENT DESIGN FOR SURVIVABILITY

      REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN


          21         1            1        M31S 2S 3 -0 -0 -0 -0 -0 -0 -0
          21         2            1        M44M41M42P 3 -0 -0 -0 -0 -0 -0
          21         3            2        M43M3AP 2 -0 -0 -0 -0 -0 -0 -0
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         PARAMETER NUMBER =  10 ELEMENT DESIGN FOR AVAILABILITY

         REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

             21         1            1        M31S 2S 3 -0 -0 -0 -0 -0 -0 -0
             21         2            1        M44M41M42P 3 -0 -0 -0 -0 -0 -0
             21         3            2        M43M38P 2 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                 LUDATF      2
*** I M S L(UERTST) ***  WARNING                 LEQT1F      2

PARAMETER NUMBER =  10

REACH NO. =  21 CAP =   3.36824E-02 SURV =   7.17283E-01 AVAIL =   9.78445E-01 ELEMENT EFF. =   2.36390E-02
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         PARAMETER NUMBER = 11 ELEMENT UESIGN FOR SURVIVABILITY

         REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

              9         1            1        S 2S 3M32 -0 -0 -0 -0 -0 -0 -0
              9         2            1        P 3M40M41M42 -0 -0 -0 -0 -0 -0
              9         3            2        P 2M39M38 -0 -0 -0 -0 -0 -0 -0
             21         1            1        M33S 2S 3 -0 -0 -0 -0 -0 -0 -0
             21         2            1        M44M41M42P 3 -0 -0 -0 -0 -0 -0
             21         3            2        M43M38P 2 -0 -0 -0 -0 -0 -0 -0
             30         1            1        M23S 2S 3 -0 -0 -0 -0 -0 -0 -0
             30         2            1        M50M28P 3 -0 -0 -0 -0 -0 -0 -0
             30         3            2        M29P 2S 4S 5 -0 -0 -0 -0 -0 -0
             30         4            2        M26P 5 -0 -0 -0 -0 -0 -0 -0 -0
             30         5            3        M53P 4 -0 -0 -0 -0 -0 -0 -0 -0
         PARAMETER NUMBER =  11 ELEMENT DESIGN FOR AVAILABILITY

         REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

              9         1            1        S 2S 3M32 -0 -0 -0 -0 -0 -0 -0
              9         2            1        P 3M40M41M42 -0 -0 -0 -0 -0 -0
              9         3            2        P 2M39M38 -0 -0 -0 -0 -0 -0 -0
             21         1            1        M33S 2S 3 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                 LUDATF      2
*** I M S L(UERTST) ***  WARNING                 LEQT1F      2
             21         2            1        M44M41M42P 3 -0 -0 -0 -0 -0 -0
             21         3            2        M43M38P 2 -0 -0 -0 -0 -0 -0 -0
             30         1            1        M23S 2S 3 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                 LUDATF      2
*** I M S L(UERTST) ***  WARNING                 LEQT1F      2
             30         2            1        M50M28P 3 -0 -0 -0 -0 -0 -0 -0
             30         3            2        M29P 2S 4S 5 -0 -0 -0 -0 -0 -0
             30         4            2        M26P 5 -0 -0 -0 -0 -0 -0 -0 -0
             30         5            3        M53P 4 -0 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                 LUDATF      2
*** I M S L(UERTST) ***  WARNING                 LEQT1F      2

PARAMETER NUMBER =  11

REACH NO. =   9 CAP =   3.62958E-02 SURV =   7.17283E-01 AVAIL =   9.78445E-01 ELEMENT EFF. =   2.54732E-02

REACH NO. =  21 CAP =   1.02833E-02 SURV =   7.17283E-01 AVAIL =   9.78445E-01 ELEMENT EFF. =   7.21783E-03

REACH NO. =  30 CAP =   8.73741E-03 SURV =   7.25916E-01 AVAIL =   9.99296E-01 ELEMENT EFF. =   6.33817E-03
```

```
PARAMETER NUMBER = 17 ELEMENT DESIGN FOR SURVIVABILITY

REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

      2         1            1        S 2S 3M34M38 -0 -0 -0 -0 -0 -0
      2         2            1        P 3M37 -0 -0 -0 -0 -0 -0 -0 -0
      2         3            2        P 2M36 -0 -0 -0 -0 -0 -0 -0 -0
     10         1            1        M35S 2S 3 -0 -0 -0 -0 -0 -0 -0
     10         2            1        M44M41M42P 3 -0 -0 -0 -0 -0 -0
     10         3            2        M43M38P 2 -0 -0 -0 -0 -0 -0 -0
     18         1            1        M21S 2S 3 -0 -0 -0 -0 -0 -0 -0
     18         2            1        M27M28P 3 -0 -0 -0 -0 -0 -0 -0
     18         3            2        M25S 4S 5P 2 -0 -0 -0 -0 -0 -0
     18         4            2        M26P 5 -0 -0 -0 -0 -0 -0 -0 -0
     18         5            3        M53P 4 -0 -0 -0 -0 -0 -0 -0 -0
     36         1            1        M24S 2S 3 -0 -0 -0 -0 -0 -0 -0
     36         2            1        M52M28P 3 -0 -0 -0 -0 -0 -0 -0
     36         3            2        M51P 2S 4S 5 -0 -0 -0 -0 -0 -0
     36         4            2        M26P 5 -0 -0 -0 -0 -0 -0 -0 -0
     36         5            3        M53P 4 -0 -0 -0 -0 -0 -0 -0 -0
 PARAMETER NUMBER =  17 ELEMENT DESIGN FOR AVAILABILITY

 REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

      2         1            1        S 2S 3M34M38 -0 -0 -0 -0 -0 -0
      2         2            1        P 3M37 -0 -0 -0 -0 -0 -0 -0 -0
      2         3            2        P 2M36 -0 -0 -0 -0 -0 -0 -0 -0
     10         1            1        M35S 2S 3 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING            LUDATF      2
*** I M S L(UERTST) ***  WARNING            LEQT1F      2
     10         2            1        M44M41M42P 3 -0 -0 -0 -0 -0 -0
     10         3            2        M43M38P 2 -0 -0 -0 -0 -0 -0 -0
     18         1            1        M21S 2S 3 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING            LUDATF      2
*** I M S L(UERTST) ***  WARNING            LEQT1F      2
     18         2            1        M27M28P 3 -0 -0 -0 -0 -0 -0 -0
     18         3            2        M25S 4S 5P 2 -0 -0 -0 -0 -0 -0
     18         4            2        M26P 5 -0 -0 -0 -0 -0 -0 -0 -0
     18         5            3        M53P 4 -0 -0 -0 -0 -0 -0 -0 -0
     36         1            1        M24S 2S 3 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING            LUDATF      2
*** I M S L(UERTST) ***  WARNING            LEQT1F      2
     36         2            1        M52M28P 3 -0 -0 -0 -0 -0 -0 -0
     36         3            2        M51P 2S 4S 5 -0 -0 -0 -0 -0 -0
     36         4            2        M26P 5 -0 -0 -0 -0 -0 -0 -0 -0
     36         5            3        M53P 4 -0 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING            LUDATF      2
*** I M S L(UERTST) ***  WARNING            LEQT1F      2

PARAMETER NUMBER =  17

REACH NO. =   2 CAP =   4.23774E-03 SURV =   2.54304E-01 AVAIL =   9.46683E-01 ELEMENT EFF. =   2.22395E-03

REACH NO. =  10 CAP =   2.16610E-03 SURV =   7.17283E-01 AVAIL =   9.78261E-01 ELEMENT EFF. =   1.51997E-03

REACH NO. =  18 CAP =   3.14209E-02 SURV =   7.25916E-01 AVAIL =   9.99296E-01 ELEMENT EFF. =   2.27929E-02

REACH NO. =  36 CAP =   3.03844E-02 SURV =   7.25916E-01 AVAIL =   9.99296E-01 ELEMENT EFF. =   2.20410E-02



 SYSTEM EFFECTIVENESS =   2.12444E-01

TOTAL COST =   5.56400E+05

COST/EFF. =   2.61904E+06
```

CANDIDATE 2.3 DATA DECK

```
CONTROL F 001020011221011120     5.     60  1.   5.    2.    .5  .25      T
USGS     01  03091500 05 0102030405
USGS     02  03094000 07 0607080910
USGS     03  03098000 25 212223242526
USGS     04  03099500 29 2728293031
USGS     05  03103500 13 1314151617181920
USGS     06  03105500 33 323334
USGS     07  03107500 36 35363738
USGS     08  03095500 11 1112
END
```

"RIBAM SDD"

```
CHAR0501         1500.
CHAR0502         1500.
CHAR0503         1500.
CHAR0504         1500.
CHAR0505         1500.
CHAR0506         1500.
CHAR0507         1500.
CHAR0508         1500.
CHAR0509         1500.
CHAR0510         1500.
CHAR0511         1500.
CHAR0512         1500.
CHAR0513          500.
CHAR0514          500.
CHAR0515          500.
CHAR0516          500.
CHAR0517          500.
CHAR0518          500.
CHAR0519          500.
CHAR0520          500.
CHAR0521         1500.
CHAR0522         1500.
CHAR0523         1500.
CHAR0524         1500.
CHAR0525         1500.
CHAR0526         1500.
CHAR0527         1500.
CHAR0528         1500.
CHAR0529         1500.
CHAR0530TT    500.        0.0417      12.5       15.0       60.0       6.75    0.25
CHAR0531          500.
CHAR0532          500.
CHAR0533          500.
CHAR0534          500.
CHAR0535          500.
CHAR0536          500.
CHAR0537          500.
CHAR0538          500.
END
CHAR1001          .005
CHAR1002          .005
CHAR1003          .005
CHAR1004          .005
CHAR1005          .005
CHAR1006          .005
CHAR1007          .005
CHAR1008          .005
CHAR1009          .005
CHAR1010          .005
CHAR1011          .005
CHAR1012          .005
```

```
CHAR1013        .0
CHAR1014        .0
CHAR1015        .0
CHAR1016        .0
CHAR1017        .0
CHAR1018        .0
CHAR1019        .0
CHAR1020        .0
CHAR1021TT   .005       0.0417      31.0       0.02       0.15       6.75    0.25
CHAR1022        .005
CHAR1023        .005
CHAR1024        .005
CHAR1025        .005
CHAR1026        .005
CHAR1027        .005
CHAR1028        .005
CHAR1029        .005
CHAR1030        .0
CHAR1031        .0
CHAR1032      0.00
CHAR1033      0.0
CHAR1034      0.0
CHAR1035      0.00
CHAR1036      0.0
CHAR1037      0.0
CHAR1038      0.0
END
CHAR1101         0.1
CHAR1102         0.1
CHAR1103         0.1
CHAR1104         0.1
CHAR1105         0.1
CHAR1106         0.1
CHAR1107         0.1
CHAR1108         0.1
CHAR1109TT   0.1        0.0417      37.00       .001       .005       6.75    0.25
CHAR1110         0.1
CHAR1111         0.1
CHAR1112         0.1
CHAR1113      0.005
CHAR1114      0.005
CHAR1115      0.005
CHAR1116      0.005
CHAR1117      0.005
CHAR1118      0.005
CHAR1119      0.005
CHAR1120      0.005
CHAR1121TT   0.1        0.0417      31.0        .001       .005       6.75    0.25
CHAR1122         0.1
CHAR1123         0.1
CHAR1124TT       0.1  0.0417    23.5      .001       .005      6.75      0.25
CHAR1125         0.1
CHAR1126         0.1
CHAR1127TT       0.1  0.0417    18.5      .001       .005      6.75      0.25
CHAR1128TT       0.1  0.0417     16.5     .001       .005      6.75      0.25
CHAR1129TT       0.1  0.0417    15.5      .001       .005      6.75      0.25
CHAR1130TT  0.005       0.0417      12.5        .001       .005       6.75    0.25
CHAR1131      0.005
CHAR1132      0.005
CHAR1133      0.005
CHAR1134      0.005
CHAR1135      0.005
CHAR1136      0.005
CHAR1137      0.005
CHAR1138   0.005
END
```

```
CHAR1701         5.0
CHAR1702TT   5.0        0.0417      82.5      0.05      0.15      6.75    0.25
CHAR1703         5.0
CHAR1704         5.0
CHAR1705         5.0
CHAR1706         5.0
CHAR1707         5.0
CHAR1708         5.0
CHAR1709         5.0
CHAR1710TT   5.0        0.0417      31.0      0.05      0.15      6.75    0.25
CHAR1711         5.0
CHAR1712         5.0
CHAR1713         5.0
CHAR1714         5.0
CHAR1715         5.0
CHAR1716TT       5.0  0.0417   44.8     0.05      0.15      6.75      0.25
CHAR1717TT       5.0 0.0417    42.4     0.05      0.15      6.75      0.25
CHAR1718TT   5.0       0.0417      36.8     0.05      0.15      6.75    0.25
CHAR1719TT       5.0 0.0417    35.6     0.05      0.15      6.75      0.25
CHAR1720         5.0
CHAR1721     5.0
CHAR1722         5.0
CHAR1723         5.0
CHAR1724         5.0
CHAR1725         5.0
CHAR1726         5.0
CHAR1727         5.0
CHAR1728         5.0
CHAR1729         5.0
CHAR1730         5.0
CHAR1731         5.0
CHAR1732         5.0
CHAR1733         5.0
CHAR1734         5.0
CHAR1735TT       5.0 0.0417    7.8      0.05      0.15      6.75      0.25
CHAR1736TT   5.0       0.0417      4.6      0.05      0.15      6.75    0.25
CHAR1737         5.0
CHAR1738         5.0
END
MTTF    21  .2       .01        5.      365.       100.      365.
MTTF    22  .2       .01        5.      365.       100.      365.
MTTF    23  .2       .01        6.      365.       100.      365.
MTTF    24  .2       .01        5.      365.       100.      365.
MTTF    25  .2       .01        3.      .3         100.      45.
MTTF    26  .01      .01        2.      .5         365.      365.
MTTF    27  .2       .01        5.      1.         137.      137.
MTTF    28  .01      .01        3.      3.         365.      365.
MTTF    29  .2       .01        3.      .3         100.      45.
MTTF    31   .2      .01        6.      365.       100.      365.
MTTF    32   .2      .01        6.      365.       100.      365.
MTTF    33   .2      .01        6.      365.       100.      365.
MTTF    34   .2      .01        5.      365.       100.      365.
MTTF    35   .2      .01        5.      365.       100.      365.
MTTF    36   .2      .01        3.      .3         100.      45.
MTTF    37   .2      .01        3.      .3         100.      45.
MTTF    38   .01     .01        2.      .5         365.      365.
MTTF    39   .2      .01        3.      .3         100.      45.
MTTF    40   .2      .01        5.      1.         137.      137.
MTTF    41   .01     .01        52.     52.          9999.     9999.
MTTF    42   .01     .01        3.      3.         365.      365.
MTTF    43   .2      .01        3.      .3         100.      45.
MTTF    44   .2      .01        5.      1.         137.      137.
MTTF    50   .2      .01        5.      1.         137.      137.
MTTF    51   .2      .01        3.      .3         100.      45.
MTTF    52    .2     .01        5.       1.       137.      137.
MTTF    53    .01     .01       2.       .5       365.      365.
MTTF    71    .2      .01      6.     365.     100.     365.
MTTF    72    .2      .01      3.     .3       100.     45.
MTTF    73    .2      .01      5.     1.       137.     137.
MTTF    74    .2      .01      6.     365.     100.     365.
MTTF    75    .2      .01      3.     .3       100.     45.
MTTF    76    .2      .01      5.     1.       137.     137.
MTTF    77    .2      .01      6.     365.     100.     365.
MTTF    78    .2      .01      3.     .3       100.     45.
MTTF    79    .2      .01      5.     1.       137.     137.
MTTF    80    .2      .01      6.     365.     100.     365.
MTTF    81    .2      .01      3.     .3       100.     45.
MTTF    82    .2      .01      5.     1.       137.     137.
MTTF    83    .2      .01      5.     365.     100.     365.
MTTF    84    .2      .01      3.     .3       100.     45.
MTTF    85   .2       .01      5.     1.       137.     137.
MTTF    86    .2      .01      5.     365.     100.     365.
MTTF    87    .2      .01      3.     .3       100.     45.
MTTF    88   .2       .01      5.     1.       137.     137.
MTTF    89    .2      .01      5.     365.     100.     365.
MTTF    90    .2      .01      3.     .3       100.     45.
MTTF    91   .2       .01      5.     1.       137.     137.
MTTF    92    .2      .01      5.     365.     100.     365.
MTTF    93    .2      .01      3.     .3       100.     45.
MTTF    94   .2       .01      5.     1.       137.     137.
END
SURV    30    05    1    1M22S02S03
SURV    30    05    2    1M50M28P03
SURV    30    05    3    2M29P02S04S05
SURV    30    05    4    2M26P05
SURV    30    05    5    3M53P04
END
AVAIL   30    05    1    1M22S02S03
AVAIL   30    05    2    1M50M28P03
AVAIL   30    05    3    2M29P02S04S05
AVAIL   30    05    4    2M26P05
AVAIL   30    05    5    3M53P04
END
SURV    21    10    1    1M31S02S03
SURV    21    10    2    1M44M41M42P03
SURV    21    10    3    2M43M38P02
END
AVAIL   21    10    1    1M31S02S03
AVAIL   21    10    2    1M44M41M42P03
AVAIL   21    10    3    2M43M38P02
END
SURV    09    11    1    1S02S03M32
SURV    09    11    2    1P03M40M41M42
SURV    09    11    3    2P02M39M38
SURV    21    11    1    1M33S02S03
SURV    21    11    2    1M44M41M42P03
SURV    21    11    3    2M43M38P02
SURV    24    11    1    1M71S02S03
SURV    24    11    2    1M73M41M42P03
SURV    24    11    3    2M72M38P02
SURV    27    11    1    1M74S02S03
SURV    27    11    2    1M76M41M42P03
SURV    27    11    3    2M75M38P02
SURV    28    11    1    1M77S02S03
SURV    28    11    2    1M79M41M42P03
SURV    28    11    3    2M78M38P02
SURV    29    11    1    1M80S02S03
SURV    29    11    2    1M82M41M42P03
SURV    29    11    3    2M81M38P02
SURV    30    11    1    1M23S02S03
SURV    30    11    2    1M50M28P03
SURV    30    11    3    2M29P02S04S05
SURV     30    11    4    2M26P05
SURV     30    11    5    3M53P04
END
AVAIL    09    11    1    1S02S03M32
AVAIL    09    11    2    1P03M40M41M42
AVAIL    09    11    3    2P02M39M38
AVAIL    21    11    1    1M33S02S03
AVAIL    21    11    2    1M44M41M42P03
AVAIL    21    11    3    2M43M38P02
AVAIL    24    11    1    1M71S02S03
AVAIL    24    11    2    1M73M41M42P03
AVAIL    24    11    3    2M72M38P0
AVAIL    27    11    1    1M74S02S03
AVAIL    27    11    2    1M76M41M42P03
AVAIL    27    11    3    2M75M38P02
AVAIL    28    11    1    1M77S02S03
AVAIL    28    11    2    1M79M41M42P03
AVAIL    28    11    3    2M78M38P02
AVAIL    29    11    1    1M80S02S03
AVAIL    29    11    2    1M82M41M42P03
AVAIL    29    11    3    2M81M38P02
AVAIL    30    11    1    1M23S02S03
AVAIL    30    11    2    1M50M28P03
AVAIL    30    11    3    2M29P02S04S05
AVAIL    30    11    4    2M26P05
AVAIL    30    11    5    3M53P04
END
SURV     02    17    1    1S02S03M34M38
SURV     02    17    2    1P03M37
SURV     02    17    3    2P02M36
SURV     10    17    1    1M35S02S03
SURV     10    17    2    1M44M41M42P03
SURV     10    17    3    2M43M38P02
SURV     16    17    1    1M83S02S03
SURV     16    17    2    1M85M28P03
SURV     16    17    3    2M84S04S05P02
SURV     16    17    4    2M53P05
SURV     16    17    5    3M26P04
SURV     17    17    1    1M86S02S03
SURV     17    17    2    1M88M28P03
SURV     17    17    3    2M87S04S05P02
SURV     17    17    4    2M53P05
SURV     17    17    5    3M26P04
SURV     18    17    1    1M21S02S03
SURV     18    17    2    1M27M28P03
SURV     18    17    3    2M25S04S05P02
SURV     18    17    4    2M26P05
SURV     18    17    5    3M53P04
SURV     19    17    1    1M89S02S03
SURV     19    17    2    1M91M28P03
SURV     19    17    3    2M90S04S05P02
SURV     19    17    4    2M53P05
SURV     19    17    5    3M26P04
SURV     35    17    1    1M92S02S03
SURV     35    17    2    1M94M28P03
SURV     35    17    3    2M93S04S05P02
SURV     35    17    4    2M53P05
SURV     35    17    5    3M26P04
SURV     36    17    1    1M24S02S03
SURV     36    17    2    1M52M28P03
SURV     36    17    3    2M51P02S04S05
SURV     36    17    4    2M26P05
SURV     36    17    5    3M53P04
END
AVAIL    02    17    1    1S02S03M34M38
AVAIL    02    17    2    1P03M37
AVAIL   02   17    3    2P02M36
AVAIL   10   17    1    1M35S02S03
AVAIL   10   17    2    1M44M41M42P03
AVAIL   10   17    3    2M43M38P02
AVAIL   16   17    1    1M83S02S03
AVAIL   16   17    2    1M85M28P03
AVAIL   16   17    3    2M84S04S05P02
AVAIL   16   17    4    2M53P05
AVAIL   16   17    5    3M26P04
AVAIL   17   17    1    1M86S02S03
AVAIL   17   17    2    1M88M28P03
AVAIL   17   17    3    2M87S04S05P02
AVAIL   17   17    4    2M53P05
AVAIL   17   17    5    3M26P04
AVAIL   18   17    1    1M21S02S03
AVAIL   18   17    2    1M27M28P03
AVAIL   18   17    3    2M25S04S05P02
AVAIL   18   17    4    2M26P05
AVAIL   18   17    5    3M53P04
AVAIL   19   17    1    1M89S02S03
AVAIL   19   17    2    1M91M28P03
AVAIL   19   17    3    2M90S04S05P02
AVAIL   19   17    4    2M53P05
AVAIL   19   17    5    3M26P04
AVAIL   35   17    1    1M92S02S03
AVAIL   35   17    2    1M94M28P03
AVAIL   35   17    3    2M93S04S05P02
AVAIL   35   17    4    2M53P05
AVAIL   35   17    5    3M26P04
AVAIL   36   17    1    1M24S02S03
AVAIL   36   17    2    1M52M28P03
AVAIL   36   17    3    2M51P02S04S05
AVAIL   36   17    4    2M26P05
AVAIL   36   17    5    3M53P04
END
COSTG    1  40000.     0.0       0.0        0.0        0
COSTG    2  10000.    25000.     0.0        0.0        1
COSTG    3  20000.    5000.      0.0       10000.      2
COSTG    4  5000.     12500.      2500.     1000.      2
COSTG    5  1000.       750.     1750.      0.         2
COSTG    6  1000.       750.      1750.     0.         2
COSTG    7  1000.     750.        1750.     0.         2
COSTG    8  10000.     25000.    .0        0.0         1
COSTG    9  20000.     5000.    0.0         10000.     8
COSTG   10  5000.     12500.     2500.      1000.      8
COSTG   11  1000.     750.       1750.      0.         8
COSTG   12  1000.     750.       1750.      0.         8
COSTG   13  1000.       750.       1750.    0.         8
COSTG   14  1000.       750.     1750.      0.         2
COSTG   15  1000.       750.     1750.      0.         2
COSTG   16  1000.       750.     1750.      0.         2
COSTG   17  1000.       750.     1750.      0.         2
COSTG   18  1000.     750.       1750.      0.         8
COSTG   19  1000.     750.       1750.      0.         8
COSTG   20  1000.     750.       1750.      0.         8
COSTG   21  1000.     750.       1750.      0.         8
COSTM   21  1200.       1000.      1000.      500.    11
COSTM   22  800.        500.       250.     100.      12
COSTM   23  3500.       1500.      1750.      500.    12
COSTM   24  1200.       1000.      1000.     500.     13
COSTM   25  1200.       100.       250.     100.      11
COSTM   26   5200.      25000.     2000.      1500.   10
COSTM   27  7000.       2000.      5000.      1000.   11
COSTM   28  45000.      2500.      5000.     20000.    9
COSTM   29  1200.       100.       250.       100.    12
COSTM   31  3500.       1500.      1750.      500.     7
COSTM  32  3500.     1500.    1750.    500.      6
COSTM  33  3500.     1500.    1750.    500.      7
COSTM  34  1200.     1000.    1000.    500.      5
COSTM  35  1200.     1000.    1000.    500.      7
COSTM  36  1200.     100.     250.     100.      5
COSTM  37  1800.     100.     250.     100.      5
COSTM  38   5200.    25000.   2000.    1500.     4
COSTM  39  1200.     100.     250.     100.      6
COSTM  40  4500.     2000.    4500.    1000.     6
COSTM  41  0.       60000.   0.        0.        3
COSTM  42  40000.    2000.    5000.    20000.    3
COSTM  43  1200.     100.     250.     100.      7
COSTM  44  4500.     2000.    4500.    1000.     7
COSTM  50  7000.     2000.    5000.    1000.    12
COSTM  51  1200.    100.      250.    100.      13
COSTM  52  7000.     2000.    5000.   1000.     13
COSTM  53  3000.    25000.   2000.     500.     13
COSTM  71  3500.     1500.    1750.    500.     14
COSTM  72  1200.     100.     250.     100.     14
COSTM  73  4500.     2000.    4500.   1000.     14
COSTM  74  3500.     1500.    1750.    500.     15
COSTM  75  1200.     100.     250.     100.     15
COSTM  76  4500.     2000.    4500.   1000.     15
COSTM  77  3500.     1500.    1750.    500.     16
COSTM  78  1200.     100.     250.     100.     16
COSTM  79  4500.     2000.    4500.   1000.     16
COSTM  80  3500.     1500.    1750.    500.     17
COSTM  81  1200.     100.     250.     100.     17
COSTM  82  4500.     2000.    4500.   1000.     17
COSTM  83  1200.     1000.    1000.    500.     18
COSTM  84  1200.     100.     250.     100.     18
COSTM  85  7000.     2000.    5000.    1000.    16
COSTM  86  1200.     1000.    1000.    500.     19
COSTM  87  1200.     100.     250.     100.     19
COSTM  88  7000.     2000.    5000.    1000.    19
COSTM  89  1200.     1000.    1000.    500.     20
COSTM  90  1200.     100.     250.     100.     20
COSTM  91  7000.     2000.    5000.    1000.    20
COSTM  92  1200.     1000.    1000.    500.     21
COSTM  93  1200.     100.     250.     100.     21
COSTM  94  7000.     2000.    5000.    1000.    21
END
#
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CANDIDATE 2.3 RESULTS

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DESIGN TYPE = F SYSTEM NUM. =    5.00 NO. OF MONTHS =    60 FLOW SCALING FACTORS =   1.0  5.0  2.0   .5   .3

STA. NO.       STA. I.D.      SEG. NO.     SEG. ASSOCIATION


   1           3091500           5         1 2 3 4 5-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

   2           3094000           7         6 7 8 910-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

   3           3098000          25        212223242526-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

   4           3099500          29        2728293031-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

   5           3103500          13        1314151617181920-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

   6           3105500          33        323334-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

   7           3107500          36        35363738-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0

   8           3045500          11        1112-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0-0
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PARAMETER NUMBER =   5
REACH NO. IMPL.   MN. PLCY.   CT      DELTA   IMPL. LOC.   EPSI     SEPSI    TUP     TDOWN


    1      F         F    1500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    2      F         F    1500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    3      F         F    1500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    4      F         F    1500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    5      F         F    1500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    6      F         F    1500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    7      F         F    1500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    8      F         F    1500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    9      F         F    1500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   10      F         F    1500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   11      F         F    1500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   12      F         F    1500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   13      F         F     500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   14      F         F     500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   15      F         F     500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   16      F         F     500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   17      F         F     500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   18      F         F     500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   19      F         F     500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   20      F         F     500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   21      F         F    1500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   22      F         F    1500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   23      F         F    1500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   24      F         F    1500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   25      F         F    1500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   26      F         F    1500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   27      F         F    1500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   28      F         F    1500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   29      F         F    1500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   30      T         T     500.000     .04     12.50     15.000   60.000    6.75     .25
   31      F         F     500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   32      F         F     500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   33      F         F     500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   34      F         F     500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   35      F         F     500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   36      F         F     500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   37      F         F     500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
   38      F         F     500.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
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PARAMETER NUMBER =  10

REACH NO. IMPL.   MN. PLCY.   CT      DELTA   IMPL. LOC.   EPSI      SEPSI     TUP     TDOWN


     1      F         F       .005    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
     2      F         F       .005    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
     3      F         F       .005    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
     4      F         F       .005    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
     5      F         F       .005    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
     6      F         F       .005    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
     7      F         F       .005    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
     8      F         F       .005    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
     9      F         F       .005    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    10      F         F       .005    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    11      F         F       .005    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    12      F         F       .005    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    13      F         F      0.000    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    14      F         F      0.000    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    15      F         F      0.000    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    16      F         F      0.000    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    17      F         F      0.000    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    18      F         F      0.000    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    19      F         F      0.000    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    20      F         F      0.000    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    21      T         T       .005      .04     31.00       .020      .150     6.75     .25
    22      F         F       .005    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    23      F         F       .005    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    24      F         F       .005    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    25      F         F       .005    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    26      F         F       .005    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    27      F         F       .005    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    28      F         F       .005    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    29      F         F       .005    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    30      F         F      0.000    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    31      F         F      0.000    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    32      F         F      0.000    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    33      F         F      0.000    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    34      F         F      0.000    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    35      F         F      0.000    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    36      F         F      0.000    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    37      F         F      0.000    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
    38      F         F      0.000    -0.00     -0.00      -0.000    -0.000    -0.00   -0.00
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PARAMETER NUMBER =  11
REACH NO. IMPL.   NO. PLCY.   CT     DELTA   IMPL. LOC.   EPSI     SEPSI    TUP     TDOWN


      1    F          F      .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
      2    F          F      .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
      3    F          F      .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
      4    F          F      .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
      5    F          F      .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
      6    F          F      .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
      7    F          F      .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
      8    F          F      .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
      9    T          T      .100     .04     37.00       .001     .005    6.75     .25
     10    F          F      .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     11    F          F      .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     12    F          F      .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     13    F          F      .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     14    F          F      .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     15    F          F      .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     16    F          F      .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     17    F          F      .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     18    F          F      .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     19    F          F      .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     20    F          F      .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     21    T          T      .100     .04     31.00       .001     .005    6.75     .25
     22    F          F      .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     23    F          F      .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     24    T          T      .100     .04     23.50       .001     .005    6.75     .25
     25    F          F      .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     26    F          F      .100   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     27    T          T      .100     .04     18.50       .001     .005    6.75     .25
     28    T          T      .100     .04     16.50       .001     .005    6.75     .25
     29    T          T      .100     .04     15.50       .001     .005    6.75     .25
     30    T          T      .005     .04     12.50       .001     .005    6.75     .25
     31    F          F      .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     32    F          F      .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     33    F          F      .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     34    F          F      .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     35    F          F      .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     36    F          F      .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     37    F          F      .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     38    F          F      .005   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
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PARAMETER NUMBER =  17
REACH NO. IMPL.   MN. PLCY.   CT     DELTA   IMPL. LOC.   EPSI     SEPSI    TUP     TDOWN

     1     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     2     T          T      5.000     .04     82.50       .050     .150    6.75     .25
     3     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     4     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     5     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     6     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     7     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     8     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
     9     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    10     T          T      5.000     .04     31.00       .050     .150    6.75     .25
    11     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    12     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    13     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    14     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    15     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    16     T          T      5.000     .04     44.80       .050     .150    6.75     .25
    17     T          T      5.000     .04     42.40       .050     .150    6.75     .25
    18     T          T      5.000     .04     36.80       .050     .150    6.75     .25
    19     T          T      5.000     .04     35.60       .050     .150    6.75     .25
    20     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    21     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    22     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    23     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    24     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    25     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    26     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    27     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    28     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    29     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    30     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    31     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    32     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    33     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    34     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    35     T          T      5.000     .04      7.80       .050     .150    6.75     .25
    36     T          T      5.000     .04      4.60       .050     .150    6.75     .25
    37     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
    38     F          F      5.000   -0.00     -0.00     -0.000   -0.000   -0.00   -0.00
```

```
                STATE 1 = OPERATING, STATE 2 = STAND-BY

MEANS NO..    MTTFS-1     MTTFS-2     MTTFA-1     MTTFA-2    MTTRA-1     MTTRA-2


    21          .20         .01         5.00      365.00     100.00      365.00
    22          .20         .01         5.00      365.00     100.00      365.00
    23          .20         .01         6.00      365.00     100.00      365.00
    24          .20         .01         5.00      365.00     100.00      365.00
    25          .20         .01         3.00         .30     100.00       45.00
    26          .01         .01         2.00         .50     365.00      365.00
    27          .20         .01         5.00        1.00     137.00      137.00
    28          .01         .01         3.00        3.00     365.00      365.00
    29          .20         .01         3.00         .30     100.00       45.00
    31          .20         .01         6.00      365.00     100.00      365.00
    32          .20         .01         6.00      365.00     100.00      365.00
    33          .20         .01         6.00      365.00     100.00      365.00
    34          .20         .01         5.00      365.00     100.00      365.00
    35          .20         .01         5.00      365.00     100.00      365.00
    36          .20         .01         3.00         .30     100.00       45.00
    37          .20         .01         3.00         .30     100.00       45.00
    38          .01         .01         2.00         .50     365.00      365.00
    39          .20         .01         3.00         .30     100.00       45.00
    40          .20         .01         5.00        1.00     137.00      137.00
    41          .01         .01        52.00       52.00    9999.00     9999.00
    42          .01         .01         3.00        3.00     365.00      365.00
    43          .20         .01         3.00         .30     100.00       45.00
    44          .20         .01         5.00        1.00     137.00      137.00
    50          .20         .01         5.00        1.00     137.00      137.00
    51          .20         .01         3.00         .30     100.00       45.00
    52          .20         .01         5.00        1.00     137.00      137.00
    53          .01         .01         2.00         .50     365.00      365.00
    71          .20         .01         6.00      365.00     100.00      365.00
    72          .20         .01         3.00         .30     100.00       45.00
    73          .20         .01         5.00        1.00     137.00      137.00
    74          .20         .01         6.00      365.00     100.00      365.00
    75          .20         .01         3.00         .30     100.00       45.00
    76          .20         .01         5.00        1.00     137.00      137.00
    77          .20         .01         6.00      365.00     100.00      365.00
    78          .20         .01         3.00         .30     100.00       45.00
    79          .20         .01         5.00        1.00     137.00      137.00
    80          .20         .01         6.00      365.00     100.00      365.00
    81          .20         .01         3.00         .30     100.00       45.00
    82          .20         .01         5.00        1.00     137.00      137.00
    83          .20         .01         5.00      365.00     100.00      365.00
    84          .20         .01         3.00         .30     100.00       45.00
    85          .20         .01         5.00        1.00     137.00      137.00
    86          .20         .01         5.00      365.00     100.00      365.00
    87          .20         .01         3.00         .30     100.00       45.00
    88          .20         .01         5.00        1.00     137.00      137.00
    89          .20         .01         5.00      365.00     100.00      365.00
    90          .20         .01         3.00         .30     100.00       45.00
    91          .20         .01         5.00        1.00     137.00      137.00
    92          .20         .01         5.00      365.00     100.00      365.00
    93          .20         .01         3.00         .30     100.00       45.00
    94          .20         .01         5.00        1.00     137.00      137.00




        PARAMETER NUMBER =  5 ELEMENT DESIGN FOR SURVIVABILITY

        REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN


            30         1            1        M22S 2S 3 -0 -0 -0 -0 -0 -0 -0
            30         2            1        M50M28P 3 -0 -0 -0 -0 -0 -0 -0
            30         3            2        M29P 2S 4S 5 -0 -0 -0 -0 -0 -0
            30         4            2        M26P 5 -0 -0 -0 -0 -0 -0 -0
            30         5            3        M53P 4 -0 -0 -0 -0 -0 -0 -0
        PARAMETER NUMBER =   5 ELEMENT DESIGN FOR AVAILABILITY

        REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN


            30         1            1        M22S 2S 3 -0 -0 -0 -0 -0 -0 -0
            30         2            1        M50M28P 3 -0 -0 -0 -0 -0 -0 -0
            30         3            2        M29P 2S 4S 5 -0 -0 -0 -0 -0 -0
            30         4            2        M26P 5 -0 -0 -0 -0 -0 -0 -0
            30         5            3        M53P 4 -0 -0 -0 -0 -0 -0 -0
 *** I M S L(UERTST) ***  WARNING                  LUDATF     2
 *** I M S L(UERTST) ***  WARNING                  LEQT1F     2

PARAMETER NUMBER =   5
REACH NO. =  30 CAP =   7.63925E-03 SURV =   7.25916E-01 AVAIL =   9.99296E-01 ELEMENT EFF. =   5.54156E-03
```

```
        PARAMETER NUMBER = 10 ELEMENT DESIGN FOR SURVIVABILITY

        REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

            21         1            1        M31S 2S 3 -0 -0 -0 -0 -0 -0 -0
            21         2            1        M44M41M42P 3 -0 -0 -0 -0 -0 -0
            21         3            2        M43M38P 2 -0 -0 -0 -0 -0 -0 -0
        PARAMETER NUMBER =  10 ELEMENT DESIGN FOR AVAILABILITY

        REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

            21         1            1        M31S 2S 3 -0 -0 -0 -0 -0 -0 -0
            21         2            1        M44M41M42P 3 -0 -0 -0 -0 -0 -0
            21         3            2        M43M38P 2 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                LUDATF     2
*** I M S L(UERTST) ***  WARNING                LEQT1F     2

PARAMETER NUMBER =  10

REACH NO. =  21 CAP =   3.36824E-02 SURV =   7.17283E-01 AVAIL =   9.78445E-01 ELEMENT EFF. =   2.36390E-02




         PARAMETER NUMBER = 11 ELEMENT UESIGN FOR SUHVIVABILITY

         REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

               9         1            1        S 2S 3M32 -0 -0 -0 -0 -0 -0 -0
               9         2            1        P 3M40M41M42 -0 -0 -0 -0 -0 -0
               9         3            2        P 2M39M38 -0 -0 -0 -0 -0 -0 -0
              21         1            1        M33S 2S 3 -0 -0 -0 -0 -0 -0 -0
              21         2            1        M44M41M42P 3 -0 -0 -0 -0 -0 -0
              21         3            2        M43M38P 2 -0 -0 -0 -0 -0 -0 -0
              24         1            1        M71S 2S 3 -0 -0 -0 -0 -0 -0 -0
              24         2            1        M73M41M42P 3 -0 -0 -0 -0 -0 -0
              24         3            2        M72M38P 2 -0 -0 -0 -0 -0 -0 -0
              27         1            1        M74S 2S 3 -0 -0 -0 -0 -0 -0 -0
              27         2            1        M76M41M42P 3 -0 -0 -0 -0 -0 -0
              27         3            2        M75M38P 2 -0 -0 -0 -0 -0 -0 -0
              28         1            1        M77S 2S 3 -0 -0 -0 -0 -0 -0 -0
              28         2            1        M79M41M42P 3 -0 -0 -0 -0 -0 -0
              28         3            2        M78M38P 2 -0 -0 -0 -0 -0 -0 -0
              29         1            1        M80S 2S 3 -0 -0 -0 -0 -0 -0 -0
              29         2            1        M82M41M42P 3 -0 -0 -0 -0 -0 -0
              29         3            2        M81M38P 2 -0 -0 -0 -0 -0 -0 -0
              30         1            1        M23S 2S 3 -0 -0 -0 -0 -0 -0 -0
              30         2            1        M50M28P 3 -0 -0 -0 -0 -0 -0 -0
              30         3            2        M29P 2S 4S 5 -0 -0 -0 -0 -0 -0
              30         4            2        M26P 5 -0 -0 -0 -0 -0 -0 -0 -0
              30         5            3        M53P 4 -0 -0 -0 -0 -0 -0 -0 -0
         PARAMETER NUMBER =  11 ELEMENT DESIGN FOR AVAILABILITY

         REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

               9         1            1        S 2S 3M32 -0 -0 -0 -0 -0 -0 -0
               9         2            1        P 3M40M41M42 -0 -0 -0 -0 -0 -0
               9         3            2        P 2M39M38 -0 -0 -0 -0 -0 -0 -0
              21         1            1        M33S 2S 3 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                  LUDATF     2
*** I M S L(UERTST) ***  WARNING                  LEQT1F     2
              21         2            1        M44M41M42P 3 -0 -0 -0 -0 -0 -0
              21         3            2        M43M38P 2 -0 -0 -0 -0 -0 -0 -0
              24         1            1        M71S 2S 3 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                  LUDATF     2
*** I M S L(UERTST) ***  WARNING                  LEQT1F     2
              24         2            1        M73M41M42P 3 -0 -0 -0 -0 -0 -0
              24         3            2        M72M38P 2 -0 -0 -0 -0 -0 -0 -0
              27         1            1        M74S 2S 3 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                  LUDATF     2
*** I M S L(UERTST) ***  WARNING                  LEQT1F     2
              27         2            1        M76M41M42P 3 -0 -0 -0 -0 -0 -0
              27         3            2        M75M38P 2 -0 -0 -0 -0 -0 -0 -0
              28         1            1        M77S 2S 3 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                  LUDATF     2
*** I M S L(VERTST) ***  WARNING                LEQT1F     2
              28        2           1        M79M41M42P 3 -0 -0 -0 -0 -0 -0
              28        3           2        M78M3PP 2 -0 -0 -0 -0 -0 -0 -0
              29        1           1        M40S 2S 3 -0 -0 -0 -0 -0 -0 -0
*** I M S L(VERTST) ***  WARNING                LUDATF     2
*** I M S L(VERTST) ***  WARNING                LEQT1F     2
              29        2           1        MA2M41M42P 3 -0 -0 -0 -0 -0 -0
              29        3           2        MA1M38P 2 -0 -0 -0 -0 -0 -0 -0
              30        1           1        M23S 2S 3 -0 -0 -0 -0 -0 -0 -0
*** I M S L(VERTST) ***  WARNING                LUDATF     2
*** I M S L(VERTST) ***  WARNING                LEQT1F     2
              30        2           1        M50M2AP 3 -0 -0 -0 -0 -0 -0 -0
              30        3           2        M29P 2S 4S 5 -0 -0 -0 -0 -0 -0
              30        4           2        M26P 5 -0 -0 -0 -0 -0 -0 -0 -0
              30        5           3        M53P 4 -0 -0 -0 -0 -0 -0 -0 -0
*** I M S L(VERTST) ***  WARNING                LUDATF     2
*** I M S L(VERTST) ***  WARNING                LEQT1F     2

PARAMETER NUMBER =  11

REACH NO. =   9 CAP =   3.62958E-02 SURV =   7.17283E-01 AVAIL =   9.78445E-01 ELEMENT EFF. =   2.54732E-02

REACH NO. =  21 CAP =   1.02833E-02 SURV =   7.17283E-01 AVAIL =   9.78445E-01 ELEMENT EFF. =   7.21783E-03

REACH NO. =  24 CAP =   4.24584E-02 SURV =   7.17283E-01 AVAIL =   9.78445E-01 ELEMENT EFF. =   2.97982E-02

REACH NO. =  27 CAP =   4.31212E-03 SURV =   7.17283E-01 AVAIL =   9.78445E-01 ELEMENT EFF. =   3.02634E-03

REACH NO. =  28 CAP =   4.58136E-02 SURV =   7.17283E-01 AVAIL =   9.78445E-01 ELEMENT EFF. =   3.21530E-02

REACH NO. =  29 CAP =   5.56351E-02 SURV =   7.17283E-01 AVAIL =   9.78445E-01 ELEMENT EFF. =   3.90459E-02

REACH NO. =  30 CAP =   3.47704E-02 SURV =   7.25916E-01 AVAIL =   9.99296E-01 ELEMENT EFF. =   2.52226E-02




       PARAMETER NUMBER = 17 ELEMENT DESIGN FOR SURVIVABILITY

       REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

            2          1            1       S 2S 3M34M38 -0 -0 -0 -0 -0 -0
            2          2            1       P 3M37 -0 -0 -0 -0 -0 -0 -0 -0
            2          3            2       P 2M36 -0 -0 -0 -0 -0 -0 -0 -0
           10          1            1       M35S 2S 3 -0 -0 -0 -0 -0 -0 -0
           10          2            1       M44M41M42P 3 -0 -0 -0 -0 -0 -0
           10          3            2       M43M3AP 2 -0 -0 -0 -0 -0 -0 -0
           16          1            1       MA3S 2S 3 -0 -0 -0 -0 -0 -0 -0
           16          2            1       MA5M2AP 3 -0 -0 -0 -0 -0 -0 -0
           16          3            2       MA4S 4S 5P 2 -0 -0 -0 -0 -0 -0
           16          4            2       M53P 5 -0 -0 -0 -0 -0 -0 -0 -0
           16          5            3       M26P 4 -0 -0 -0 -0 -0 -0 -0 -0
           17          1            1       MA6S 2S 3 -0 -0 -0 -0 -0 -0 -0
           17          2            1       MA8M28P 3 -0 -0 -0 -0 -0 -0 -0
           17          3            2       MA7S 4S 5P 2 -0 -0 -0 -0 -0 -0
           17          4            2       M53P 5 -0 -0 -0 -0 -0 -0 -0 -0
           17          5            3       M26P 4 -0 -0 -0 -0 -0 -0 -0 -0
           18          1            1       M21S 2S 3 -0 -0 -0 -0 -0 -0 -0
           18          2            1       M27M28P 3 -0 -0 -0 -0 -0 -0 -0
           18          3            2       M25S 4S 5P 2 -0 -0 -0 -0 -0 -0
           18          4            2       M26P 5 -0 -0 -0 -0 -0 -0 -0 -0
           18          5            3       M53P 4 -0 -0 -0 -0 -0 -0 -0 -0
           19          1            1       MA9S 2S 3 -0 -0 -0 -0 -0 -0 -0
           19          2            1       M91M2AP 3 -0 -0 -0 -0 -0 -0 -0
           19          3            2       M90S 4S 5P 2 -0 -0 -0 -0 -0 -0
           19          4            2       M53P 5 -0 -0 -0 -0 -0 -0 -0 -0
           19          5            3       M26P 4 -0 -0 -0 -0 -0 -0 -0 -0
           35          1            1       M92S 2S 3 -0 -0 -0 -0 -0 -0 -0
           35          2            1       M94M2AP 3 -0 -0 -0 -0 -0 -0 -0
           35          3            2       M93S 4S 5P 2 -0 -0 -0 -0 -0 -0
           35          4            2       M53P 5 -0 -0 -0 -0 -0 -0 -0 -0
           35          5            3       M26P 4 -0 -0 -0 -0 -0 -0 -0 -0
           36          1            1       M24S 2S 3 -0 -0 -0 -0 -0 -0 -0
           36          2            1       M52M28P 3 -0 -0 -0 -0 -0 -0 -0
           36          3            2       M51P 2S 4S 5 -0 -0 -0 -0 -0 -0
           36          4            2       M26P 5 -0 -0 -0 -0 -0 -0 -0 -0
           36          5            3       M53P 4 -0 -0 -0 -0 -0 -0 -0 -0
```

```
        PARAMETER NUMBER =  17 ELEMENT DESIGN FOR AVAILABILITY

        REACH NO.  PATH NO.   NORMAL STATUS  ELEMENT DESIGN

              2          1             1       S 2S 3M34M38 -0 -0 -0 -0 -0 -0
              2          2             1       P 3M37 -0 -0 -0 -0 -0 -0 -0 -0
              2          3             2       P 2M36 -0 -0 -0 -0 -0 -0 -0 -0
             10          1             1       M35S 2S 3 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                  LUDATF     2
*** I M S L(UERTST) ***  WARNING                  LEQT1F     2
             10          2             1       M44M41M42P 3 -0 -0 -0 -0 -0 -0
             10          3             2       M43M38P 2 -0 -0 -0 -0 -0 -0 -0
             16          1             1       M83S 2S 3 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                  LUDATF     2
*** I M S L(UERTST) ***  WARNING                  LEQT1F     2
             16          2             1       M85M28P 3 -0 -0 -0 -0 -0 -0 -0
             16          3             2       M84S 4S 5P 2 -0 -0 -0 -0 -0 -0
             16          4             2       M53P 5 -0 -0 -0 -0 -0 -0 -0 -0
             16          5             3       M26P 4 -0 -0 -0 -0 -0 -0 -0 -0
             17          1             1       M86S 2S 3 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                  LUDATF     2
*** I M S L(UERTST) ***  WARNING                  LEQT1F     2
             17          2             1       M88M28P 3 -0 -0 -0 -0 -0 -0 -0
             17          3             2       M87S 4S 5P 2 -0 -0 -0 -0 -0 -0
             17          4             2       M53P 5 -0 -0 -0 -0 -0 -0 -0 -0
             17          5             3       M26P 4 -0 -0 -0 -0 -0 -0 -0 -0
             18          1             1       M21S 2S 3 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                  LUDATF     2
*** I M S L(UERTST) ***  WARNING                  LEQT1F     2
             18          2             1       M27M28P 3 -0 -0 -0 -0 -0 -0 -0
             18          3             2       M25S 4S 5P 2 -0 -0 -0 -0 -0 -0
             18          4             2       M26P 5 -0 -0 -0 -0 -0 -0 -0 -0
             18          5             3       M53P 4 -0 -0 -0 -0 -0 -0 -0 -0
             19          1             1       M89S 2S 3 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                  LUDATF     2
*** I M S L(UERTST) ***  WARNING                  LEQT1F     2
             19          2             1       M91M28P 3 -0 -0 -0 -0 -0 -0 -0
             19          3             2       M90S 4S 5P 2 -0 -0 -0 -0 -0 -0
             19          4             2       M53P 5 -0 -0 -0 -0 -0 -0 -0 -0
             19          5             3       M26P 4 -0 -0 -0 -0 -0 -0 -0 -0
             35          1             1       M92S 2S 3 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                  LUDATF     2
*** I M S L(UERTST) ***  WARNING                  LEQT1F     2
             35          2             1       M94M28P 3 -0 -0 -0 -0 -0 -0 -0
             35          3             2       M93S 4S 5P 2 -0 -0 -0 -0 -0 -0
             35          4             2       M53P 5 -0 -0 -0 -0 -0 -0 -0 -0
             35          5             3       M26P 4 -0 -0 -0 -0 -0 -0 -0 -0
             36          1             1       M24S 2S 3 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                  LUDATF     2
*** I M S L(UERTST) ***  WARNING                  LEQT1F     2
             36          2             1       M52M28P 3 -0 -0 -0 -0 -0 -0 -0
             36          3             2       M51P 2S 4S 5 -0 -0 -0 -0 -0 -0
             36          4             2       M26P 5 -0 -0 -0 -0 -0 -0 -0 -0
             36          5             3       M53P 4 -0 -0 -0 -0 -0 -0 -0 -0
*** I M S L(UERTST) ***  WARNING                  LUDATF     2
*** I M S L(UERTST) ***  WARNING                  LEQT1F     2

PARAMETER NUMBER =  17

REACH NO. =   2 CAP =   9.23774E-03 SURV =   2.54304E-01 AVAIL =   9.46683E-01 ELEMENT EFF. =   2.22395E-03

REACH NO. =  10 CAP =   2.16616E-03 SURV =   7.17283E-01 AVAIL =   9.78261E-01 ELEMENT EFF. =   1.51997E-03

REACH NO. =  16 CAP =   2.17199E-03 SURV =   7.25916E-01 AVAIL =   9.99229E-01 ELEMENT EFF. =   1.57547E-03

REACH NO. =  17 CAP =   2.06497E-02 SURV =   7.25916E-01 AVAIL =   9.99229E-01 ELEMENT EFF. =   1.49784E-02

REACH NO. =  18 CAP =   3.14209E-02 SURV =   7.25916E-01 AVAIL =   9.99296E-01 ELEMENT EFF. =   2.27929E-02

REACH NO. =  19 CAP =   4.68920E-02 SURV =   7.25916E-01 AVAIL =   9.99229E-01 ELEMENT EFF. =   3.40135E-02

REACH NO. =  35 CAP =   3.03844E-02 SURV =   7.25916E-01 AVAIL =   9.99229E-01 ELEMENT EFF. =   2.20396E-02

REACH NO. =  36 CAP =   4.96172E-02 SURV =   7.25916E-01 AVAIL =   9.99296E-01 ELEMENT EFF. =   3.59926E-02
```

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